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AIMP D AND E MAGNETIC FIELD ANALYSIS

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GODDARD SPACE FLIGHT CENTER
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ABSTRACT

The Goddard Space Flight Center has flown triaxial fluxgate magnetometers on board AIMP'S D and E, launched in July, 1966 and 1967, respectively. The digital data tapes from these experiments provide the initial inputs to the AIMP D and E Data Processing System. The first stage of this processing system, the Phase I Analysis, converts the raw sensor data to magnetic units, merges it with the trajectory data, rotates to solar ecliptic and other useful coordinate systems and computes statistics. In addition to providing plots of the raw data, subsequent computer programs in the system smooth the data, sort it by time and remove any time overlap. The AIMP E data receive additional processing to correct for errors in magnetic field azimuth in the optical shadow of the moon. The resulting final summary data tapes are then used to generate hourly averages, spectra and automatic plots in various formats.

This document describes the programs comprising the processing system, including instructions for the use of the programs, the formats of AIMP data tapes, and examples of output.

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AIMP D AND E MAGNETIC FIELD ANALYSIS

I. INTRODUCTION

A. INSTRUMENTATION

AIMP D (Explorer 33) was launched from the Eastern Test Range, Cape Kennedy, Florida on July 1, 1966 at 1602:25 UT. Initial orbital characteristics were: Apogee = 440,300 km, perigee = 51,000 km, and orbital period = 12 days. The initial spin rate was 26.5 rpm. AIMP E (Explorer 35) was launched from the Eastern Test Range on July 19, 1967 at 1419:02 UT. It was placed into selenocentric orbit on July 22, 1967 with aposelene = 9388 km, periselene = 2568 km, and period = 11.5 hours. Initial spin rate = 28.0 rpm.

The GSFC magnetic field experiment on both AIMPs D and E consists of a triaxial fluxgate magnetometer with the three sensors mounted together in an orthogonal configuration at a remote distance from the spacecraft on a boom support. A flipper mechanism reorienting the sensor set by 90° once each day provides frequent reversal of the spin axis or Z sensor for in-flight zero calibration along that axis. In-flight zero level calibration of the X and Y sensors, which are perpendicular to the spin axis, is accomplished by utilizing the spin of the spacecraft. The sensitivity and linearity of each sensor is checked each 12 hours by the addition of a known magnetic field parallel to the sensor axis.

The dynamic range of the AIMP D magnetometer is $\pm 64\gamma$ ($1\gamma = 10^{-5}$ oersted) along each axis with a sensitivity of $\pm 0.25\gamma$. A new feature incorporated into the AIMP E instrument is an automatic range switch that changes the sensitivity on the basis of in-flight measurements. The two ranges are $\pm 24\gamma$ and $\pm 64\gamma$ on each axis, with sensitivities of ± 0.18 and $\pm 0.25\gamma$, respectively. On both spacecraft a measurement of the ambient vector magnetic field is performed once every 5.11 seconds and the results are stored until the next readout period.

More comprehensive descriptions of the instrumentation may be found in Behannon (1967) and Ness et al. (1967).

B. TELEMETRY

Explorers 33 and 35 employ a pulse frequency modulation (PFM) telemetry system (Rochelle, 1962). The continuous telemetry stream is built up of individual telemetry sequences, each of which are 81.808 seconds in length. Each sequence is divided into 256 channels with 16 channels constituting one frame. Thus there are 16 frames per sequence. This channel-frame array is shown in Figure 1 for both AIMPs D and E. The channels are numbered from 0 to 15 horizontally, and the frames are numbered from 0 to 15 vertically. Each channel contains two bursts of information (burst A and burst B).

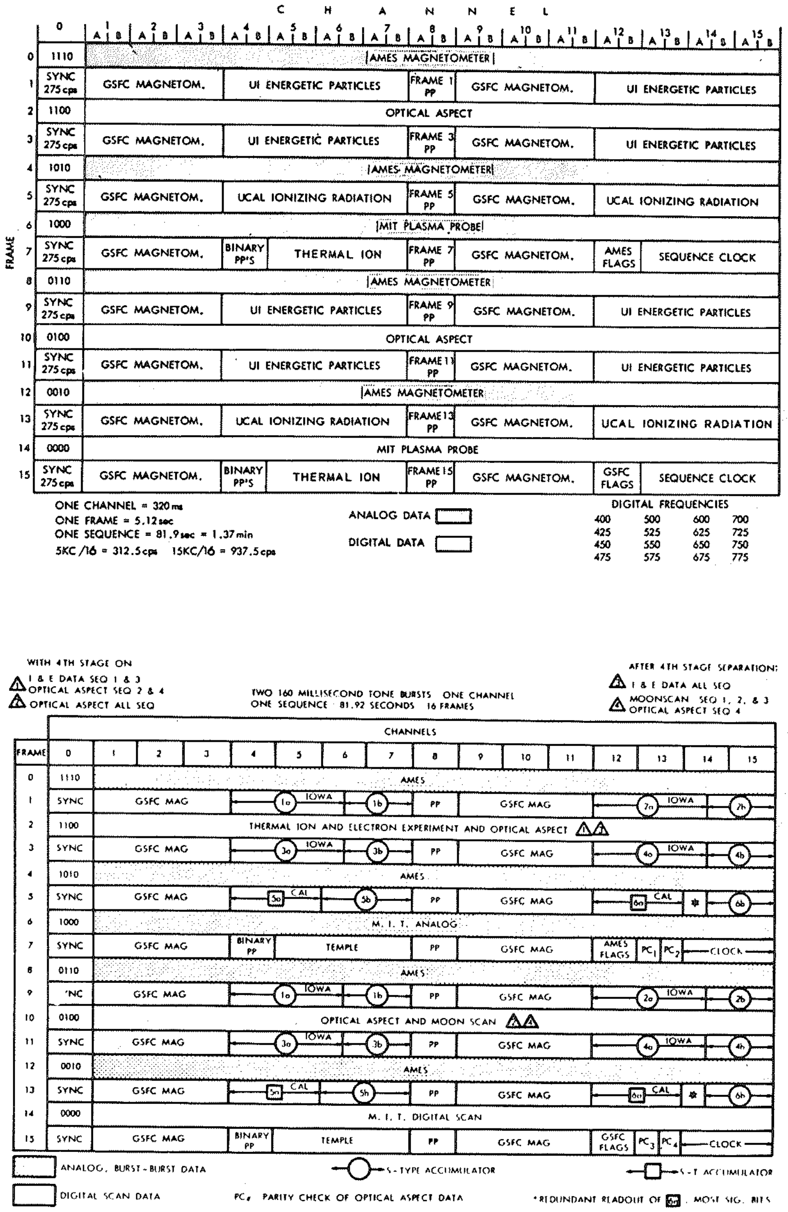


Figure 1. AIMP D (top) and E Encoder Formats

For reasons of format simplification the magnetic field sampling was chosen to be synchronous with the telemetry rate rather than with the spin rate of the spacecraft. A measurement of the vector field is performed once every frame of 5.11 seconds in channel 4. The magnetometer sensors are sampled, digitized and buffer stored in less than 15 milliseconds. The stored values from the three sensors are read out four bits at a time during channels 1-3 and 9-11 of the odd numbered frames every sequence. The telemetry is digitized by the F8 Data Processing System (Heffner, 1965a,b).

C. GENERAL DESCRIPTION OF DATA PROCESSING

Following a calibration analysis the magnetic field measurements (Experimenter Tape) and spacecraft trajectory data (on a separate Trajectory Tape) are processed with the Phase I Data Analysis Program. This program converts the raw sensor data in engineering units into magnetic field units, merges the magnetic field and trajectory data, rotates the vector measurements from the rotating spacecraft coordinate system to a fixed payload frame of reference and then further into solar ecliptic and solar magnetospheric coordinates, computes averages and standard deviations for each telemetry sequence (sequence statistics), and finally produces a raw binary summary tape in addition to printed output on both the printer unit and microfilm. This can be seen in Figure 2, which gives a comprehensive picture of the total AIMP D and E processing scheme.

The raw summary tape (1), is used to produce SC 4020 sequence statistic plots on both microfilm and hard copy. Then it is subjected to a series of refining steps that include smoothing (elimination of noisy data points), a sorting of the data by time to merge overlapping data from different experimenter tape files, and finally removal of the overlap by selecting the best of redundant sequences according to standard deviation, data quality, and number of good points per sequence. The best sequence in each such case is written on the final summary tape and the worst sequence is eliminated.

As can be seen in Figure 2, the final summary tape (4) for AIMP D can be utilized as input for various higher level analysis and plot programs. AIMP E data consisting of measurements performed in the optical shadow of the moon contain errors in the direction of the magnetic field due to the absence of a true sun pulse on the satellite during the shadow (Taylor, 1968). Thus it is necessary to subject the AIMP E data to a stage of correction processing in order to obtain a corrected final summary tape (4'). Each phase of the processing is described in detail in Part II. Some of the programs that plot or perform further analysis on data from final summary tapes 4 and 4' are also discussed in that section.

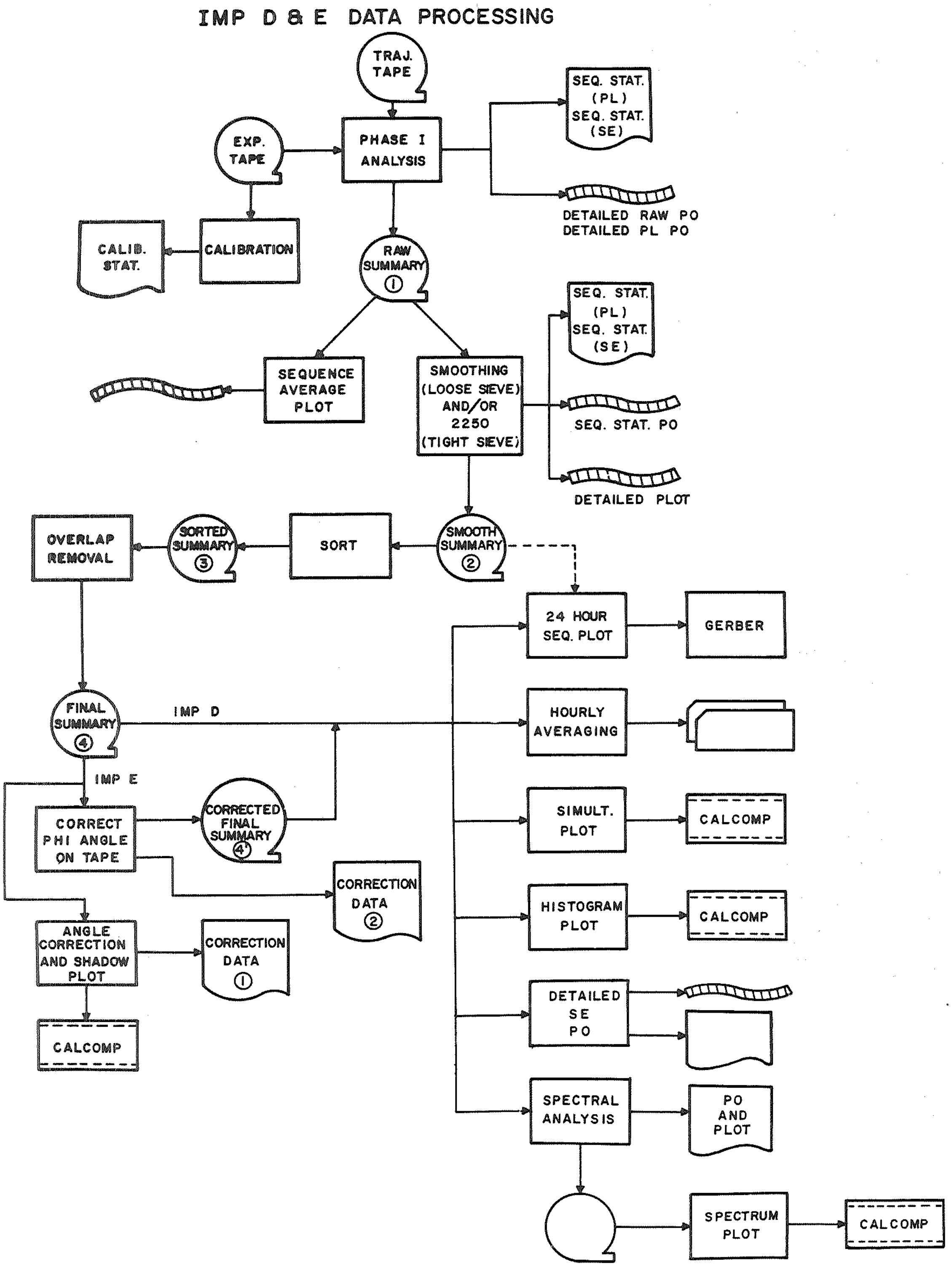


Figure 2. AIMP D and E Data Processing System

II. DETAILED DESCRIPTION OF PROCESSING

A. CALIBRATION

Upon receipt from the Information Processing Division the GSFC magnetic field experimenter tapes for AIMPs D and E (see Appendix A for format) are initially subjected to a calibration analysis. A data tape is scanned for calibration and sensor reorientation (flip) events. These occur at uniform multiples of telemetry sequence clock counts. Calibrations occur at intervals of 512 sequences (twice daily) and reorientation or flips at intervals of 1024 sequences (once daily). Around these events the 16 data values in each telemetry sequence from each of the sensors in the plane of rotation are fitted by a least squares technique, and the DC level, amplitude and phase of the fitted cosine wave as well as the root-mean-square error of the best fit are obtained. This technique is described in detail in Appendix B.

The DC levels for each sensor are averaged to provide a daily zero level for that sensor. This information is used in the subsequent analysis of the magnetic field data. The zero levels determined in this manner are accurate to within $\pm 0.2\gamma$.

The least squares method breaks down when the sampling period is an integral multiple of the spin period of the satellite. During the week of October 22-28 the spin period of AIMP D passed through a value of 2.5566 seconds which is exactly half the sampling period. The least squares fit results were completely spurious for that week and for the week on each side the RMS deviations of the fit were on the average greater than those computed prior to that three week interval by as much as an order of magnitude. Interpolated zero levels were used for those three weeks. The zero levels changed by no more than 0.2γ across that interval.

A check on the sensitivities of the sensors is obtained from the fit to the data around the time when the calibration currents are on at the sensors. The difference in the DC level when the current is on provides an incremental magnetic field and hence a measure of the sensitivity.

The respective calibration program decks will read the AIMP D or E experimenter tapes and print both sun time and spin period data, and calibration data (for definitions of sun time, raw spin period and refined spin period, see Taylor, 1968). For each fourth sequence for which there is usable spin and sun data there is a printout of sequence clock count, the number of fourth sequences since the last usable data, the current sun time, the last good sun time, the first difference of these sun times, the raw spin period, and the computed refined spin period. The sun time differences are useful in detecting erroneous sun time values. The calibration data printed include sensor zeros and least squares fit amplitudes as well as the phase of the fitted cosine wave, the number of data points used in the fit (N), the RMS deviation of the fit, and the experiment flags which denote sensor orientation and whether or not the flipper heater is on (Appendix C). The calibration data are printed out for 5 sequences around each calibration event and for 21 sequences around flip events. Average zeros, amplitudes and RMS deviations are computed for each such set of sequences and printed.

The calibration program was written for the IBM 360 computer in FORTRAN language. The input is the seven track GSFC experimenter data tape. The control cards are as follows:

(1) Run year, run day, process year, process day (Format: I2, I3, I2, I3).

The days used are decimal day of the year. Run data are obtained from the ID listing that comes with experimenter tapes. Process date is date of calibration.

(2) Initial spin period in counts, spin test tolerance (Format: F5.0, F5.2).

For initial spin period use last spin period printed out in calibration of previous week of data. Tolerance can be left at the same value always (like 0.1).

(3) Calibration event base clock, flip event base clock (Format: F6.0, F6.0).

These base clocks are the sequence clocks at which initial calibration and flip events occurred. Any later events occur at clock values which are equal to these base values plus a multiple of 512 for calibrates and a multiple of 1024 for flips. They will remain the same unless the spacecraft turns off and then on again. Then new initial base clocks will have to be established. They have to be at least 2 events prior to the first events on the experimenter tape to be analyzed. Specially selected bases for times other than flip or calibrate events may also be used if desired.

(4) Minimum value of N for a sequence to be acceptable for inclusion in the zero averages, maximum value of RMS acceptable for same purpose, number of files of the experimenter tape to be processed (Format: 15, F5.2, 15).

DD cards for IBM System 360 processing of this and the other programs discussed in this document are listed in Appendix H. The average zeros obtained from this analysis are plotted and handfitted with curves giving smoothly varying zeros for each of the experiment sensors as functions of time.

B. PHASE I ANALYSIS

Both the magnetic field experimenter tapes and the trajectory tapes are inputs to the Phase I Data Analysis Program (PDAP) which runs on the IBM 360/75J. The formats of the experimenter and trajectory tapes are given in Appendices A and D, respectively. The Phase I program performs the following operations on the data:

(1) The zero levels and the slopes of the calibration curves for each sensor are used to convert the data from engineering units to magnetic field units (gammas). For the ith component the conversion has the form

$$D_i \text{ (gammas)} = D_i \text{ (e.u.)} - Z_i\, S_i ,$$

where Z_i is the zero level for the ith component in engineering units and S_i is the slope of the linear part of the calibration curve for that sensor (which is valid over the range of field magnitudes being measured).

(2) Magnetic field magnitudes are computed from each of the set of outputs (D_1, D_2, D_3) from the three sensors using

$$F = \sqrt{D_1^2 + D_2^2 + D_3^2} .$$

(3) The field component data are transformed from the triaxial sensor frame of reference to a reference frame $(X, Y, Z)_A$ that rotates with the spacecraft but is stationary with respect to sensor reorientation.

(4) The data are further transformed from the rotating frame of reference to a fixed, payload reference frame $(X, Y, Z)_p$. The payload frame is a right-handed coordinate system defined such that the Z_p azis is colinear with the spin axis of the satellite and positive above the spacecraft. The mutually perpendicular X_p and Y_p axes lie in the equatorial plane of the spacecraft, with the X_p axis always in the plane defined by the satellite-sun vector and the spin axis.

(5) The next transformation rotates the data from the payload reference frame into the solar ecliptic frame, which is a useful coordinate system for studying interplanetary phenomena.

(6) The payload field components are also rotated into the solar magnetospheric coordinate system, which is useful in studies of the geomagnetic tail. This earth-centered right-handed system of coordinates is defined such that the X_{SM} axis always points toward the sun, and the Z_{SM} axis is directed so that the $X_{SM}\, Z_{SM}$ - plane always contains the geomagnetic dipole axis. Thus Y_{SM} is always orthogonal to both the earth-sun line and the geomagnetic dipole axis.

The rotation matrices utilized in each of the above transformations are given in Appendix E. The computation of the angle of rotation from spinning to fixed coordinates is also described, including the compensation for instrumental phase-shift.

The PDAP further computes sequence averages of the magnetic field magnitude and of the vector components in each of the reference frames. These are linear averages over the 16 or less individual magnitude or component values present in each 81.808 second telemetry sequence. Occasionally data values are missing because of telemetry signal noise. These are replaced by 9999. on the experimenter tape. For each average value that is computed for the total field or field component, the corresponding root-mean-square deviation over the telemetry sequence period is also computed, using the average and the N good data values, according to the relation

$$\mathrm{BRMS} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (B_i - \bar{B})^2} \; .$$

These deviations are measures of the high frequency fluctuations of the field.

Other diagnostic quantities which are computed are:

(1) Total field ratio,

$$\mathrm{FRATIO} = \frac{\text{sequence total field RMS deviation}}{\text{sequence average total field magnitude}} \; ;$$

(2) Component ratio,

$$\text{CRATIO} = \frac{\text{BRMS}\left(X_{SE}\right) + \text{BRMS}\left(Y_{SE}\right) + \text{BRMS}\left(Z_{SE}\right)}{3\sqrt{\overline{BX}_{SE}^{2} + \overline{BY}_{SE}^{2} + \overline{BZ}_{SE}^{2}}} ,$$

where BX_{SE} is the sequence average of the solar ecliptic X component of the field and $\text{BRMS}\left(X_{SE}\right)$ is the corresponding sequence root-mean-square deviation.

The sequence average solar ecliptic field components are also used to compute the orientation of the magnetic field vector in terms of the solar ecliptic azimuthal and latitudinal angles ϕ_{SE} and θ_{SE}. These are given by

$$\phi_{SE} = \tan^{-1}\left(\frac{\overline{BY}_{SE}}{\overline{BX}_{SE}}\right) ,$$

$$\theta = \tan^{-1}\left(\frac{\overline{BZ}_{SE}}{\sqrt{\overline{BX}_{SE}^{2} + \overline{BY}_{SE}^{2}}}\right) .$$

The AIMP D and E trajectory tapes include spacecraft positions in both solar ecliptic and solar magnetospheric coordinates at five minute intervals. The PDAP linearly interpolates between these five minute positions to obtain the corresponding position of the satellite for each set of sequence average data.

The final function of the program is to generate the raw binary summary tapes containing all of the computed 5.11 second and sequence average data. The format of the AIMP binary summary tapes is given in Appendix F. Printed output is obtained on both the printer unit (sequence statistics) and on microfilm (detailed raw and payload data (see Appendix H). A flowchart of the PDAP is shown in Figure 3.

Inputs to the Phase I analysis (which is written in FORTRAN language) are the seven track GSFC experimenter tapes and the seven track AIMP trajectory tapes. Switch settings and certain parameter values are input to the program on data cards. These are described below.

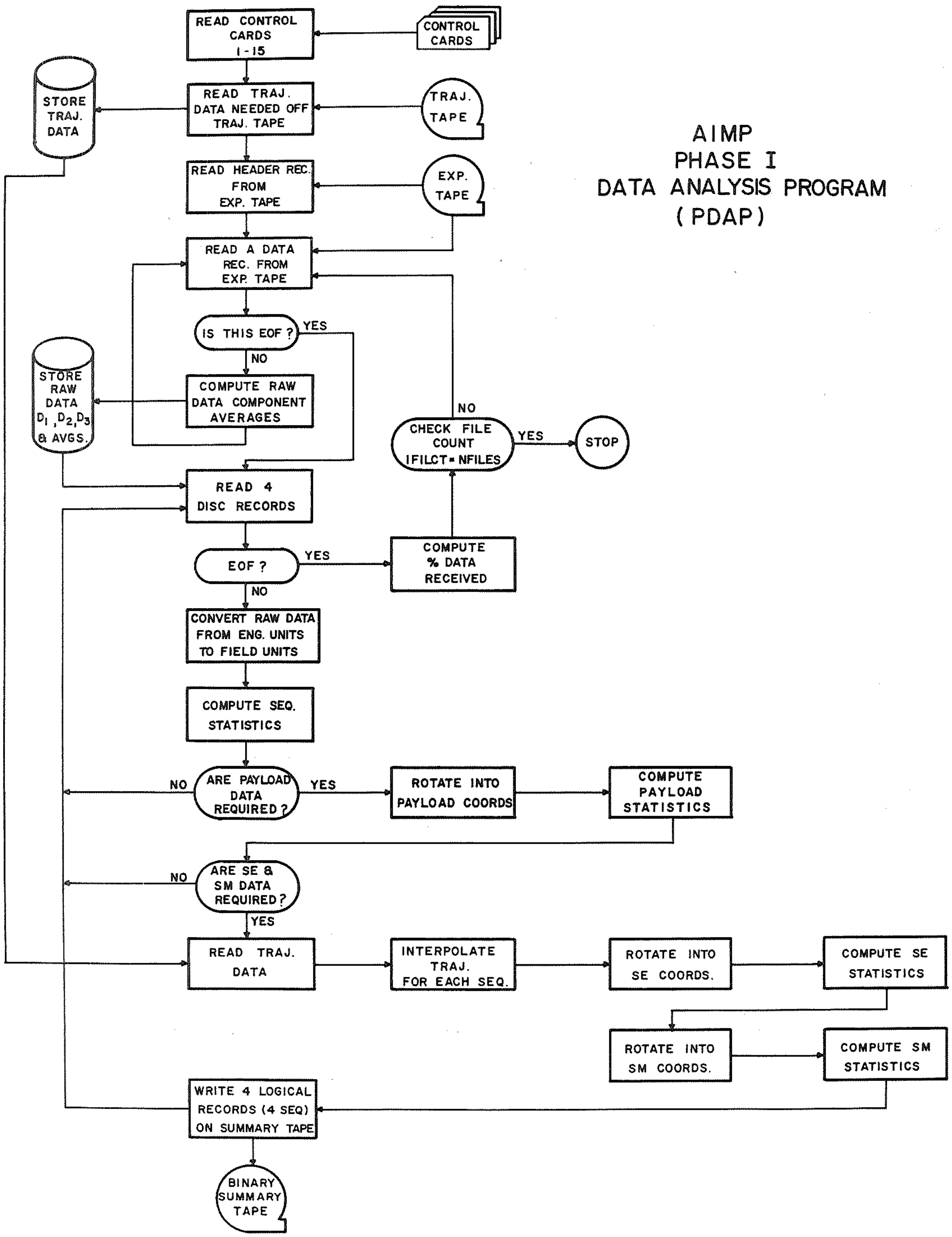


Figure 3. Phase I Analysis Flowchart

(1) Switching Vector

Each two column field on the card is one component or switch of the vector S. The values of these switches determine the processing paths followed by the analysis program.

S_1 (Col. 2): 0 - Do not compute payload data.
1 - Continue computation into payload coordinates.

S_2 (Col. 4): 0 - Do not print raw data.
1 - Print raw data.

S_3 (Col. 6): 0 - Print detailed payload results.
1 - Print payload sequence statistics.
2 - Print both payload formats.

S_4 (Col. 8): 0 - Do not compute SE and SM data.
1 - Skip payload print and print only SE and SM.
2 - Print both payload and ecliptic (which payload format depends on S_3).

S_5 (Col. 10): 0 - Read data from trajectory tape.
1 - Do not read trajectory data (use only when $S_4 = 0$).

S_6 (Col. 12): 0 - dummy.

S_7 (Col. 14): 0 - Do not test sequence clock number.*
1 - Test sequence clock number.

S_8 (Col. 16): 0 - Do not write binary summary tape.
1 - Write binary summary tape.

S_9 (Col. 18): 0 - Do not print detailed SE data.
1 - Print detailed SE data.

(2) The zero levels and slopes for conversion of sensor outputs from engineering units (counts) to gammas for the first day of the week of data being

*If $S_7 = 1$ the sequence clock number will be compared with the value for the previous sequence. If the difference is greater than a specified tolerance (see data Card No. 12) the SE and SM computation for that sequence will be bypassed. General practice has been to use $S_7 = 0$.

processed. In the case of AIMP E these are the first day zeros and slopes for the low (0-24γ) range. They are punched on the card as follows:

Mnemonics	Cols.	Description
ZEROZ	1-5	$Z(D_3)$ zero level
SLOPEZ	6-11	$Z(D_3)$ slope
ZEROY	12-16	$Y(D_2)$ zero level
SLOPEY	17-22	$Y(D_2)$ slope
ZEROX	23-27	$X(D_1)$ zero level
SLOPEX	28-33	$X(D_1)$ slope

Format: 3 (F5.1, F6.4)

The zero levels are derived from the calibration analysis output.

(3) Same as card No. 2 except that for AIMP D the zeros and slopes on this card are used when sensor outputs go above a specified threshold THRESH (defined in the program and presently set = 255 counts). For AIMP E the data on this card will be used when the instrument switches from low to high (64γ) range (when the sensor output exceeds 238 counts or goes below 17 counts). They have the mnemonics

ZERO2Z, SLP2Z, ZERO2Y, SLP2Y, ZERO2X, SLP2X.

(4-6) Decimal day times at which the zero levels are to be updated, and the new set of zeros for each of the given times.

The times used correspond to the start of each day's sensor reorientation (flip) and are obtained from the calibration analysis printout. The cards contain seven sets of data. It is important for proper operation of the program that the seventh time value used be larger than any time included on the experimenter tape being analyzed. Therefore to be completely safe the usual practice is to set T(7) = 999.0.

Mnemonics: T(I), ZZ(I), ZY(I), ZX(I), I = 1, 7

Format of each card: 3(F 11.5, 3F 5.1).

(7-8) Zero levels for the times given in cards 4-6, to be used when AIMP D sensor outputs exceed THRESH and when AIMP E sensors switch into the high range. As long as THRESH = 255 cards 7-8 for AIMP D are only dummy cards. In that case the zero levels on those cards will not be used and thus the values on those cards need only be some arbitrary set of constants.

Mnemonics: ZZ2(I), ZY2(I), ZX2(I), I = 1, 7

Format of each card: 4 (3F 5.1).

(9) Year and day of the year experimenter tape received, and year and day that analysis is run.

Mnemonics: IRYR, IRDAY, IPYR, IPDAY

Format: 2 (I2, I3).

(10) Constants used in the computation of instrumental phase shift.

Mnemonics: C1, C2 for AIMP D
C1, C2, C3, C4 for AIMP E

Format: 4 F9.7.

(11) Calibration fields for each of the three sensors.

Mnemonics: XCAL, YCAL, ZCAL

Format: 3F 5.1.

(12)

Mnemonics	Cols.	Description
ESPIN	1-5	Starting value of spin period in 800 cps clock counts.*
TOL	6-10	Tolerance for testing spin period.†
KTEST	11-14	Largest acceptable deviation acceptable in sequence clock test.
KPLOTN	15-16	Dummy

Format: F 5.0, F 5.2, I4, I2.

*Obtained from calibration analysis.

†Each spin period on experimenter tape is tested before it is used. If it differs by more than the fraction TOL from ESPIN at the beginning or from the previous value used throughout the remainder of the data then it is not updated.

(13)

Mnemonics	Cols.	Description
NFILES	1-2	Number of files of data to be processed.
ISKIP	3-4	Number of files to skip over before starting processing.

Format: 2I2.

(14) Initial clock on tape, to initialize testing of clock numbers (see S7 of switching vector).

Mnemonic	Cols.
KCLK	1-6

Format: I6.

(15) Decimal day start and stop times for the interval of trajectory data to be read off tape and stored on disk.

Mnemonics	Cols.	Description
STCD	1-12	Trajectory start time.
SPCD	13-24	Trajectory stop time.

Format: 2F12.8.

C. SC 4020 PLOT OF SEQUENCE STATISTICS

The sequence statistics on the raw AIMP D and E Summary Tapes are plotted using the SC 4020 Microfilm Plotter. This provides a useful first-look presentation of all the raw data. Figure 4 is an example of one frame of the microfilm plot. Each frame contains six hours of sequence average field magnitude (F), field angles ϕ and θ (in either solar ecliptic or solar magnetospheric coordinates), and magnitude standard deviation (FRMS). The F range is 0-25γ, the ϕ range is 0°-360°, the θ range is -90° to +90° and the FRMS range is 0-10γ. The corresponding spacecraft position in either SE or SM coordinates is given at the beginning of each hour along the abscissa. In the case of AIMP E the geocentric position is given each three hours in addition to the hourly selenocentric positions.

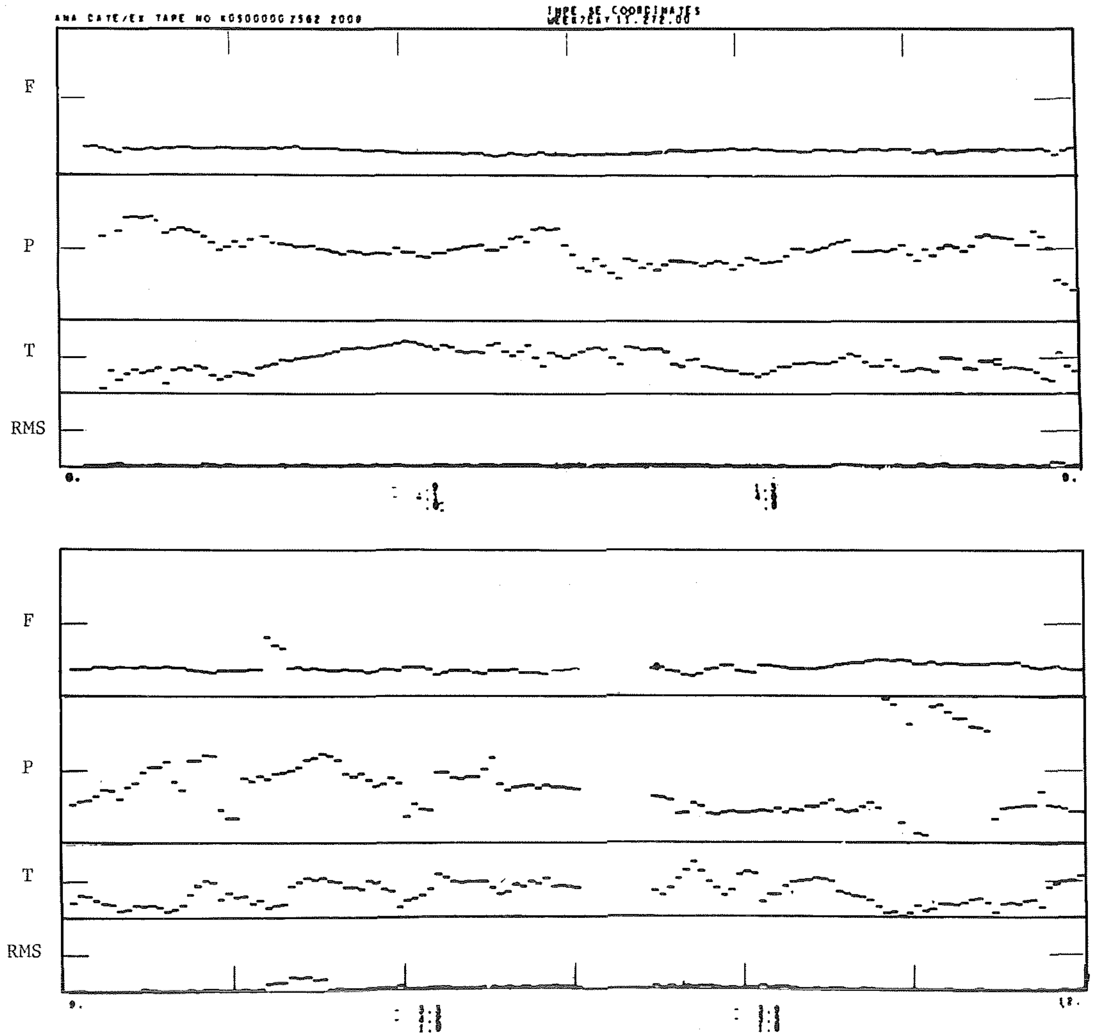


Figure 4. SC 4020 Sequence Statistics Plot

The plot program was written for the IBM 360 in FORTRAN language. The input is a nine track binary summary tape. There are two versions of the program to handle different level input tapes. The version generally used reads the raw summary tape, which is logically blocked, four sequences per block, by the PDAP. Another version available for use reads either smoothed, sorted or final summary tapes which are all blocked only by the Job Control of the system.

The one control card required by the program contains the following data:

Cols.	Description
1-2	01 selects SM coordinates; 02 selects SE.
3-4	Week of data.
5-8	Summary Tape Number.
9-12	Process date (calendar day of year, last digit of year).

Format: 2I2, 2A4.

For these plots hard copy is always requested in addition to the microfilm.

D. SMOOTHING

Two separate methods have been developed for deleting spurious data points from the raw summary tapes and removing the effects of such points from the sequence statistics on those tapes.

1. AUTOMATIC (LOOSE SIEVE)

The first method is completely automatic and consists simply of detecting detailed (5.11 sec) data values which differ by more than some pre-set tolerance from neighboring points. This is done by testing and comparing successive first differences of the field magnitude values for the magnitude and sign of the change between detailed points. Appropriate values are then deleted (replaced by 999.0) when tests indicate that the tolerance has been exceeded. When a field magnitude value has been deleted, the program automatically deletes the corresponding BX, BY and BZ in all coordinate systems and recomputes sequence statistics when all data in the sequence have been checked. In principle such a scheme can be made highly discriminating, but in practice it is used only as a "loose sieve," i.e., with a large tolerance in order to prevent the deletion of sizable but physically real variations of the field.

In addition to correcting the data for the effects of noisy data points, the program tests to see if the number of good points in each sequence is less than a given value or if the data quality flag exceeds a certain value. If either condition is detected, then all of the data in the sequence will be deleted. A new "smoothed" summary tape is produced by the program. It also produces a printout identical in format to that produced by the PDAP for payload and solar ecliptic sequence statistics. This printout is written on both the printer unit and on microfilm for long term storage (see Appendix H).

This program was written for the IBM 360 computer in FORTRAN language. The inputs are the nine track raw summary tapes produced by the AIMP D and E Phase I Analysis Programs. The output in each case is a nine track tape in summary tape format (see Appendix F). The control cards are as follows:

(1)

Mnemonics	Cols.	Description
NMIN	1-3	Minimum number of good points allowed per sequence.
IDQMAX	4-6	Maximum allowed data quality flag.
RMSTOL	7-11	RMS tolerance used to determine if a sequence needs smoothing.
DTOL	12-16	Difference tolerance (gammas) for deletion of data points.

Format: I3, I3, F5.2, F5.2.

(2)

Mnemonics	Cols.	Description
IDATE	1-6	Date in month (1-2), day (3-4), and year (5-6) that job is run.
IL1	7-8	Alphabetic designation of input tape (such as FP).
IT1	9-12	Library number of input tape.
IL2	13-14	Alphabetic designation of output tape.
IT2	15-18	Library number of output tape.
STTM	19-25	Decimal day start time of data on tape.

Mnemonics	Cols.	Description
SPTM	26-32	Decimal day stop time of tape.
ISTSQ	33-38	Clock number of initial sequence.
ISPSQ	39-44	Clock number of final sequence.

Format: I6, A2, I4, A2, I4, F7.3, F7.3, I6, I6.

The data on the second card are used only as ID information in the printout page headings.

A separate function performed by this smoothing program is the writing of a plot tape for the SC 4020 Microfilm Plotter. The 5.11 sec detailed data are plotted (F, θ and ϕ, where the angles have been computed from the detailed solar ecliptic cartesian coordinate data) one hour of data per frame. Figure 5 is an example of one frame of the detailed microfilm plot. The F range is 0-25γ, the θ range is -90° to +90°, and the ϕ range is 0°-360°.

2. 2250 DISPLAY (TIGHT SIEVE)

A method of smoothing which permits a tightening of the discrimination process employs the IBM 2250 Display Scope. Sequence statistics from the summary tapes are plotted on the scope. Individual sequences which appear to be spurious can then be visually detected and selected for detailed display. In this manner the individual points which distort the averages can be identified and deleted. New statistics are then automatically computed and replace the old statistics on the "smoothed" summary tape. With knowledge on the part of the 2250 operator of the amount and intensity of physically real fluctuations or variations to be expected in the data at a given point on the tape, a judgment can be made in each individual case concerning the level of tolerance to be used. This "tight sieve" can be applied to raw summary data or to data which already have been subjected to loose sieving.

The 2250 Smoothing Program is resident on the graphics disk. Steps to be followed in the initiation of a job are as follows*:

(1) Turn on scope

(2) Hit any key

*These steps apply to operation under the Graphics Supervisor on the IBM 360/75J. When operating on the IBM 360/91 the initial step (after turning on scope) is to use the light pen to select the length of intervals to be plotted (one, two or three hours).

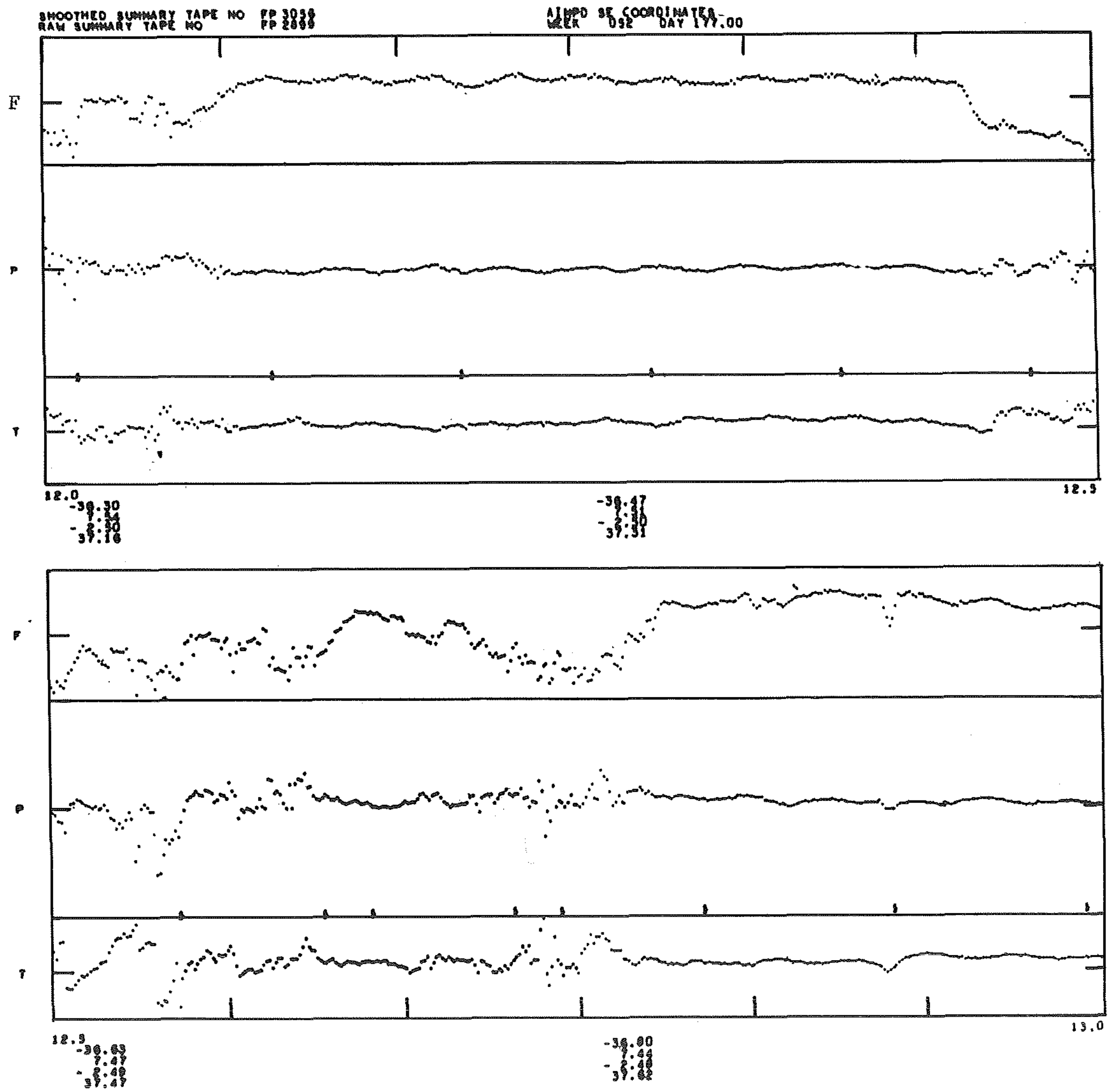


Figure 5. SC 4020 Detailed Data Plot

(3) Fill in the following information on the scope:

ID ____________________

ACCOUNT ______________

DD CARD ______________ (leave blank)

NAME _________________

(4) Depress KEY 1.

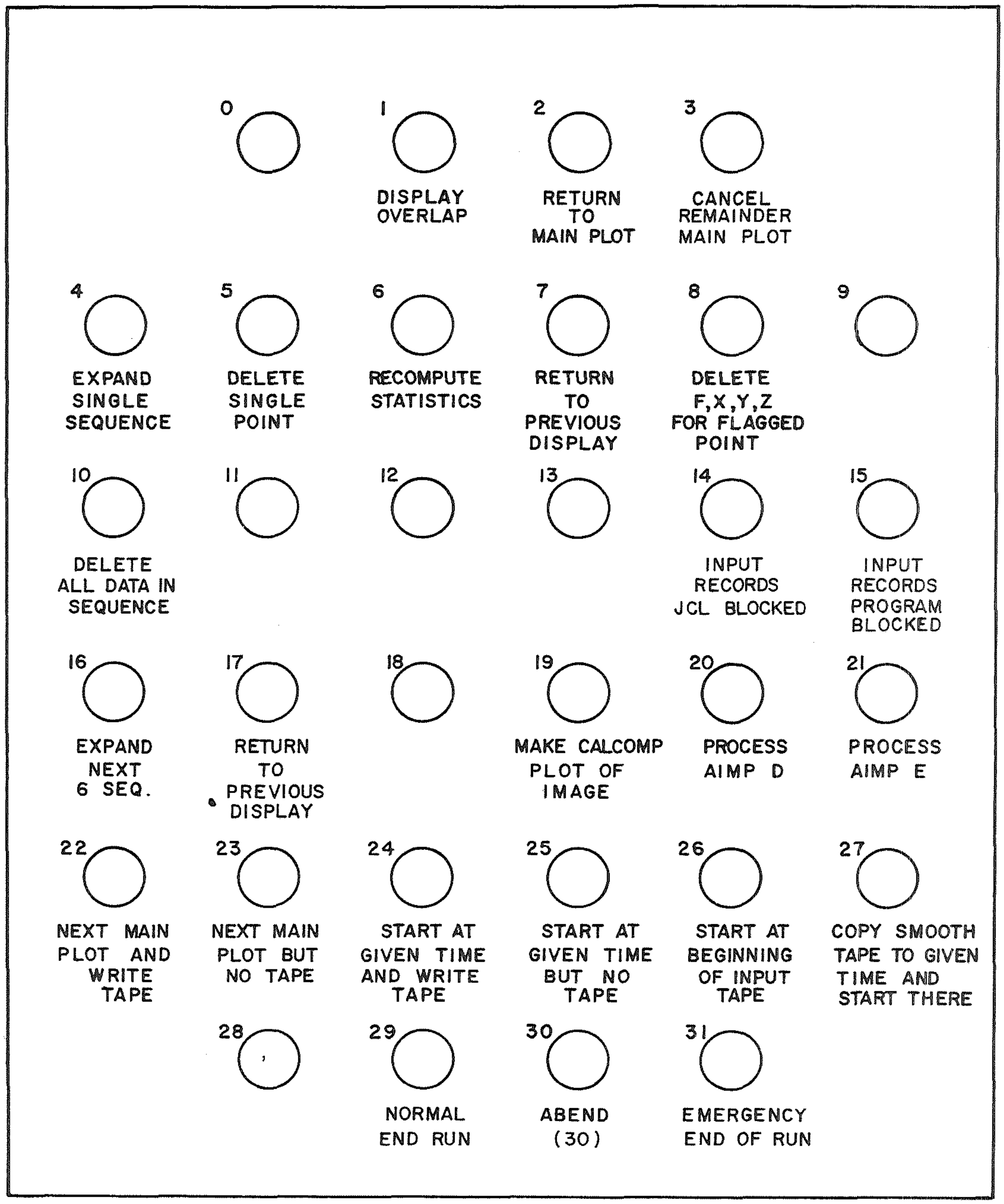
The program will call for the operator to mount the first tape (input) the first time it attempts to read data. It will likewise call for the output tape when it first attempts to write a new tape.

The basic display consists of sequence statistics (F, θ, ϕ sequence averages and FRMS) for a time interval of three hours*. This is called the MAIN PLOT. Selection of any one of the four points for a given sequence with the light pen after depression of the appropriate key will produce an expanded plot of the detailed points in that sequence (F, BX, BY, BZ). Using the light pen and the proper key each individual spurious 5.11 sec field measurement can be deleted. When all bad points in the sequence have been eliminated, a recomputation of the sequence statistics is called for by key. A display of the same three hour period of sequence statistics will show the effects of the smoothing. When the entire interval is satisfactorily smoothed the next three hours of sequence statistics can be displayed while the smoothed data is written on the new summary tape. An entire sequence can be deleted if no acceptable improvement in its statistics is possible.

Two other displays are available. They are a special expanded display of data that overlaps in time, and an expanded plot of six consecutive sequences. In the latter plot the first sequence of the set of six to be displayed must be identified with the light pen. This plot is to assist in the investigation of data processing problems connected with the updating of certain parameters, such as the spin period, once every four sequences.

Figure 6 shows the 2250 key functions for this program. After job initiation a selection must be made between keys 20 and 21, followed by a selection from keys 25-27. Subsequent calls for a new main plot display require a selection from keys 22-25. For a more detailed description of this program and its operation see Howell (1968).

*This interval can be varied to one or two hours at any time during the job. The message on the screen which is used to select a new interval is called up by depressing the light pen foot pedal.



PROGRAMMED FUNCTION KEYBOARD
FOR IBM 2250 DATA SMOOTHING

Figure 6. IBM 2250 Function Keys For Data Smoothing*

*For greater convenience the functions of keys 5 and 8 have been interchanged since the drafting of this figure. Also add the function for key 11 of deleting all points inclusive between two points which are flagged with the light pen.

E. SORT AND OVERLAP REMOVAL

The AIMP D and AIMP E sort programs run on the IBM 360 system. File names for the input and output tapes, respectively, are SORTIN and SORTOUT. The sort program orders the records (sequence data) of the smoothed summary tapes with respect to time, utilizing the IBM prepared Sort, Merge program. The field used to control the sort is the sequence decimal day time, which is a double precision, floating point word. The 2314 Disk File is utilized for work units in the interest of speed. Four work units are required to execute. Output of this program is designated as the "sorted" summary tape.

The sort output tape is then input to the overlap removal program. The sort program will have merged data from the overlapping period between two adjacent files on the original experimenter tape so that two records corresponding to the same telemetry sequence will now be adjacent. If for any pair of successive records A and B

$$\text{(sequence time of A - sequence time of B)} \leq 10^{-5},$$

then the program will consider the two records to be overlapping data for the same sequence. If that is the case then the records will be tested and compared on the basis of number of digitized data points, data quality flag, and field magnitude standard deviation. The values of these three quantities are separately compared to preset tolerances for the two records and switches set by the results of those tests. If all values are within tolerances then the decision on which record to keep is made on the basis of direct comparison of the magnitude standard deviations. If equality is found there then data quality flags, and finally number of points if necessary, are directly compared. The record containing the best data for the given sequence is written on the "overlap removed" summary tape and the other record is deleted.

The program control card contains the following data:

Cols.	Description
1-2	Minimum number of digitized data points acceptable.
3-6	Maximum value of magnitude RMS deviation acceptable.
7	Maximum value of data quality flag acceptable.

Format: I2, F4.1, I1.

F. PHI ANGLE CORRECTION FOR AIMP E

Each time AIMP E passes through the shadow of the moon, cooling causes an inward contraction of the solar paddles and results in a small, temporary secular decrease in spin period during the pass. Thus the pseudo-sun pulse generated when the spacecraft is in the shadow no longer accurately indicates the sunward direction. Because of this erroneous spin information the rotation to payload coordinates in the PDAP no longer leads to the correct azimuth for the magnetic field measured in the shadow. This makes it necessary to correct the magnetic field azimuth when the spacecraft is in the shadow. The procedure used has been described in detail by Taylor (1968).

The angle correction can be implemented in two separate and independent stages to produce

(1) Plots of the corrected data;

(2) Corrected Final Summary Tapes.

Both programs use the correction procedure developed by Taylor and are described in the following paragraphs.

1. SHADOW PLOT

The Angle Correction and Shadow Plot Program is used to read the Explorer 35 summary tapes and produce a Calcomp plot of the sequence average magnetic field measurements in the lunar wake. The plot covers a time period of almost 3-1/2 hours and is centered on the time of the optical shadow. The parameters plotted include magnitude, latitude angle and longitude angle of the field in a spin axis oriented coordinate system (approximately selenocentric solar ecliptic), as well as other representations of the field in a natural coordinate system where the X axis is the same but the Y and Z axes lie in and normal to the plane defined by the average field and the sun direction (X_{se} axis) respectively. The position of the spacecraft is ticked in at regular intervals and the period when the spacecraft is in the optical shadow of the moon is identified. A sample plot is shown in Figure 7. In addition to the plot a listing is produced which includes the raw data from the summary tape, the corrections made in the lunar shadow, the average field before, during and after the traversal of the wake and the corrected data in each of three natural coordinate systems based respectively on the three different average fields computed.

Detailed explanations of the printout and of the plots are given in Appendix G. The program needs two inputs: one a set of cards specifying the time to be plotted

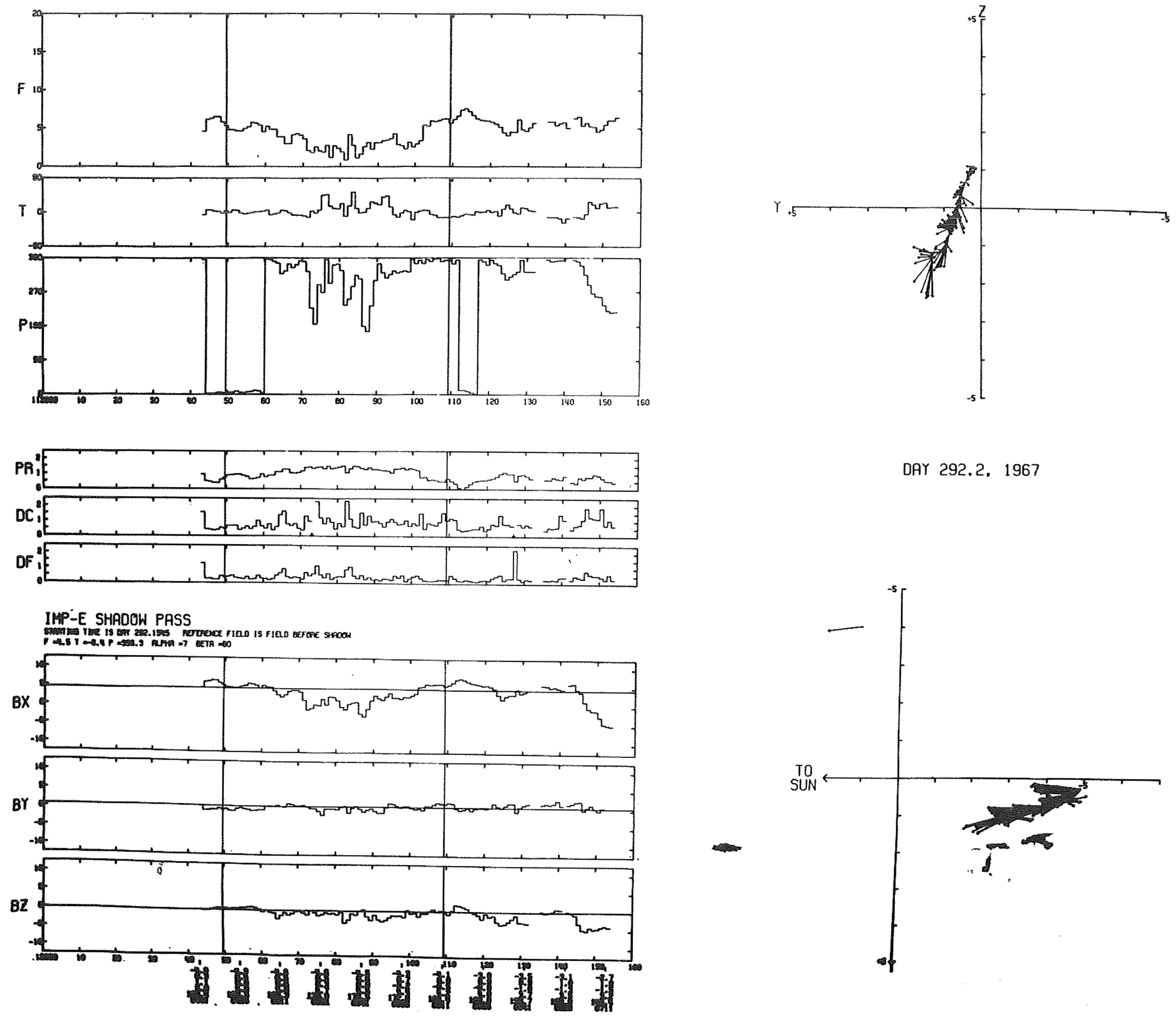


Figure 7. AIMP E Shadow Plot

and also providing the parameters needed to correct the azimuth angle in the optical shadow of the moon; the second the summary tape. The card input is described in the following table.

Mnemonic	Columns	Description
	Card #1	
SEQSHA	1-10	Number of the first sequence in shadow
SLTH	11-20	Number of sequences in shadow
DTSI	21-30	Decimal day of first sequence in shadow
	Card #2	
DTS	1-10	Number of sequences in shadow (same as SLTH on card 1)
DTI	11-20	Number of sequences between last sequence 4 before shadow and beginning of shadow (Count the 9 at the beginning)*
DTF	21-30	Number of sequences between end of shadow and next sequence 4 (Don't count the 9 at end).
PI	31-40	Refined spin period before last sequence 4 before shadow
PF1	41-50	Refined spin period after first sequence 4 after shadow
PF2	51-60	Refined spin period after second sequence 4 after shadow
CI	61-70	Last good sun time before shadow (in last sequence 4 before shadow)
CF	71-80	First good sun time after shadow (in first sequence 4 after shadow)
	Card #3	
SP	1-10	Raw spin period (in clock counts)
RSPSI	11-20	Refined spin period used before first sequence 4 in the shadow
RSPS	21-30	Refined spin period used in shadow

*This refers to counting sun flags for each half sequence. The flag for the last half of a sequence 4 is always a 9.

Mnemonic	Columns	Description
RSPSF	31-40	Refined spin period used after last sequence 4 in the shadow
SEQI	41-50	Number of last sequence 4 before shadow
ID	51-78	Alphameric data to identify the shadow pass - Example: DAY 208.2, 1967 ORBIT 13.

Format: 2I10, F15.6/8F10.6/5F10.6, 7A4.

Spin periods should be given to six decimal places e.g. 2.291234.

In cases where it is unclear from the sun flags whether the given sun time is real or pseudo, comparison of the refined spin periods will resolve the ambiguity. The last spin period before the shadow which is different from the spin period used in the middle of the shadow (RSPS) follows the last good sun time. Similarly the first spin period at the end of the shadow which is different from RSPS preceeds the first real sun time after the shadow.

2. SUMMARY TAPE CORRECTION

The AIMP E PHI Angle Correction (PAC) Program corrects the payload and solar ecliptic azimuth angle of the magnetic field and the X, Y components of the field when the spacecraft is in the lunar shadow. A corrected summary tape is produced, and corrected solar ecliptic data are printed out. These include the correction angle and corrected sequence average PHI angles for each shadow pass, along with the corrected detailed ϕ_{SE}, BX_{SE}, and BY_{SE} values for each sequence, the average BX_{SE} and BY_{SE} data, and flags to indicate if the field line through the satellite also intersects the moon. If D is the distance in kilometers of the field line from the surface of the moon, the following table gives the range of D represented by each possible value of the flag, which is given in the last column of the printout.

FLAG	LOWER BOUND	UPPER BOUND	FLAG	LOWER BOUND	UPPER BOUND
0	moon center	-200 km	5	0 km	50 km
1	-200	-150	6	50	100
2	-150	-100	7	100	150
3	-100	- 50	8	150	200
4	- 50	0	9	200	250
			blank	250	∞

This program was written for the IBM 360 computer in FORTRAN language. The input is the nine track AIMP E smoothed, sorted and overlap-removed (final) summary tape. The output tape is identical to the input tape except that the appropriate data have been corrected for the effects of the spinup in the lunar shadow.

Input data cards for the program are the same as those listed in the preceding section for the Shadow Plot Program except that the first card must also contain the following information:

Mnemonic	Columns	Description
T1	36-60	Decimal time of last sequence 4 before shadow to six decimal places. (The sequence for which the clock is given in SEQI on card #3)

Format: F 15.6.

This can be punched on the card when it is prepared for the Shadow Plot Program.

G. HOURLY AVERAGING

This program was written in FORTRAN language for the IBM 360 computer. It reads the AIMP D and E Final Summary Tapes and uses the sequence statistic data inclusive in each hour to compute hourly average solar ecliptic and solar magnetospheric magnetic field components and field magnitude. Only sequences which satisfy tests on the magnitude standard deviation, the data quality flag, and the number of data points digitized are used in the averages. If the number of suitable sequences in a given hour is less than a specified minimum then no averages are computed for that hour.

When average magnitude and components are computed the program also computes magnitude and component standard deviations for that hour. Field orientation angles ϕ and θ are computed from the component averages in the selected (SE or SM) coordinate system. The program then punches hourly average data cards containing the computed data as well as date, time and trajectory data and also prints these data. Averages are also computed of the individual sequence ϕ and θ values, and these are included in the last two columns of the printout.

The input data card required by the program contains the following information:

Mnemonics	Columns	Description
KORB	1-3	Week number of input data.
RMSMAX	4-9	Maximum acceptable FRMS for a sequence.
IDZMAX	10-12	Maximum acceptable data quality flag.
NMIN	13-15	Minimum number of sequences for which an average is computed.
ISTSQ	16-22	Start sequence number for interval of input data to be averaged.
ISPSQ	23-29	Stop sequence no.
MSW	30-31	If = 1, SE cards punched; otherwise SM cards punched.
LOW	32-34	Minimum number of digitized data points/ sequence that is acceptable.

Format: I3, F6.2, 2I3, 2I7, I2, I3.

The data contained in the hourly average cards punched by the program and the format of those cards are as follows:

Mnemonics	Columns	Description
KORB	1-2	Week number.
RAD	3-7	Radial distance of spacecraft in earth radii (all trajectory data correspond to position of spacecraft at the center point of the hour).
XSE(XSM)	8-12	Solar ecliptic (magnetospheric) X coordinate of spacecraft.
YSE(YSM)	13-17	SE(SM) Y coordinate.
ZSE(ZSM)	18-22	SE(SM) Z coordinate.
JYR	23-24	Year of data on card.
JDAY	25-27	Day of data on card.
JHR	28-29	Hour of data on card.

Mnemonics	Columns	Description
FHAV	30-34	Hourly average field magnitude (to 0.1 gamma).
THAV	35-39	Hourly average θ_{SE} (θ_{SM}) to nearest degree).
PHAV	40-44	Hourly average ϕ_{SE} (ϕ_{SM}) (to nearest degree).
XEHAV (XMHAV)	45-49	Hourly average BX_{SE} (BX_{SM}) (X component of field, to 0.1 gamma).
YEHAV(YMHAV)	50-54	Hourly average BY_{SE} (BY_{SM}).
ZEHAV(ZMHAV)	55-59	Hourly average BZ_{SE} (BZ_{SM}).
XRMS	60-64	Standard deviation of BX (to 0.1 gamma).
YRMS	65-69	Standard deviation of BY.
ZRMS	70-74	Standard deviation of BZ.
AVF	75-79	Field magnitude computed from hourly average field components.

Format: I2, 4F5.1, I2, I3, I2, F5.1, 2F5.0, 7F5.1.

There is a Modified Hourly Average Program for AIMP E which does not compute averages when data are from measurements made in the optical shadow of the moon. This program can be used to punch hourly average cards from uncorrected Final Summary Tapes since it will exclude from the averages the shadow data corresponding to erroneous azimuth information.

The hourly average data can be plotted using the Hourly Average Histogram Plot program. This was written in FORTRAN Language for the IBM 360 computer and produces a plot tape for the Calcomp 770 or 780 Automatic Plotter. The program control card contains the following information:

Mnemonics	Columns	Description
DAYON	1-3	Decimal day data starts.
NUMB	4-6	Number of additional days of data to be plotted (beyond first day).
PLOT1	7-10	Type of plot (If 'ANGL' will plot F, θ, ϕ; if 'BOTH' will also plot BX, BY, BZ components).

Mnemonic	Columns	Description
SCALE(1)	11-20	Scale in inches/hour of the plot (0.08334 gives 2 in/day).

Format: 2I5, A4, F10.5.

The control card is followed by the set of hourly average data cards to be plotted. Following the last of these data cards there must be an additional card with -9 in columns 1-2 to properly terminate the plot.

There will always be two files on the plot tape. The first file contains the grid and the magnitude computed from the hourly average components (AVF). The second file contains the remainder of the plot.

H. DETAILED SE OR SM COMPONENT PRINTOUT

The PDAP provides on option the detailed printout of raw and/or payload component data. This detailed component print program must be used in order to obtain a similar detailed printout of individual data points in solar ecliptic (SE) or solar magnetospheric (SM) coordinates. The program was written in FORTRAN language for the IBM 360 computer. The input is a nine track AIMP D or E summary data tape.

The control card for the program consists of (1) the start clock (sequence number) for the selection of data to be printed; (2) the stop clock or termination sequence for that section; (3) either a 1 for the printing of SE data or a 2 to select printout of SM data. The format of the card is 3I6. The output can be printed either directly when the job is executed or on microfilm by appropriate choice of DD cards (see Appendix H).

I. OTHER PLOT PROGRAMS

There are three additional programs available for producing automatic plots of AIMP D and E sequence statistics. They were all written in FORTRAN language for the IBM 360 computer. There is also a fourth program which plots AIMP E detailed magnitude data through lunar shadow passes.

1. GERBER POINT PLOT

The Gerber Plot Program reads a smoothed summary tape (or any post-smoothing summary tape) and produces a tape to plot sequence statistics as points on the Gerber 822 Automatic Plotter. Each plot produced by the program consists of one day (or less) of data. Each time the day number changes on the input tape, a new plot is started. Figure 8 illustrates the type of plot produced. It consists of the solar ecliptic orientation angles of the magnetic field θ and ϕ as well as the field magnitude F and the magnitude standard deviation. Trajectory data are printed at the bottom. The program control card contains the following information:

(1) Maximum value of data quality flag allowed for a sequence to be plotted;

(2) Minimum number of good data points allowed for a sequence to be plotted.

The card format is 2I2.

2. CALCOMP HISTOGRAM PLOT

A Calcomp Histogram Plot Program has been described in Section F for plotting AIMP E data in the optical shadow of the moon. Separate decks of this program have been prepared which will produce a similar plot on the Calcomp 770 or 780 Plotter of sequence average F, θ and ϕ and a vector in the XY and YZ planes for AIMP D and also for IMP F (marked IMP D and IMP F, respectively). As described in Section F these plots cover a time period of almost 3-1/2 hours (150 sequences for AIMP D and 600 sequences for IMP F). They are most suitable for plotting data from AIMP D and IMP F that is simultaneous to a shadow pass by AIMP E, although other time intervals may be plotted as well.

Input cards may be the same as those used in the Shadow Plot Program or they may contain the following information:

Card	Columns	Description
1	1-10	Sequence no. at middle of interval to be plotted.
	11-20	Nothing.
	21-35	Decimal day time of sequence at middle of interval to be plotted.
2		Anything, but must be present.
3		Anything, but must be present.

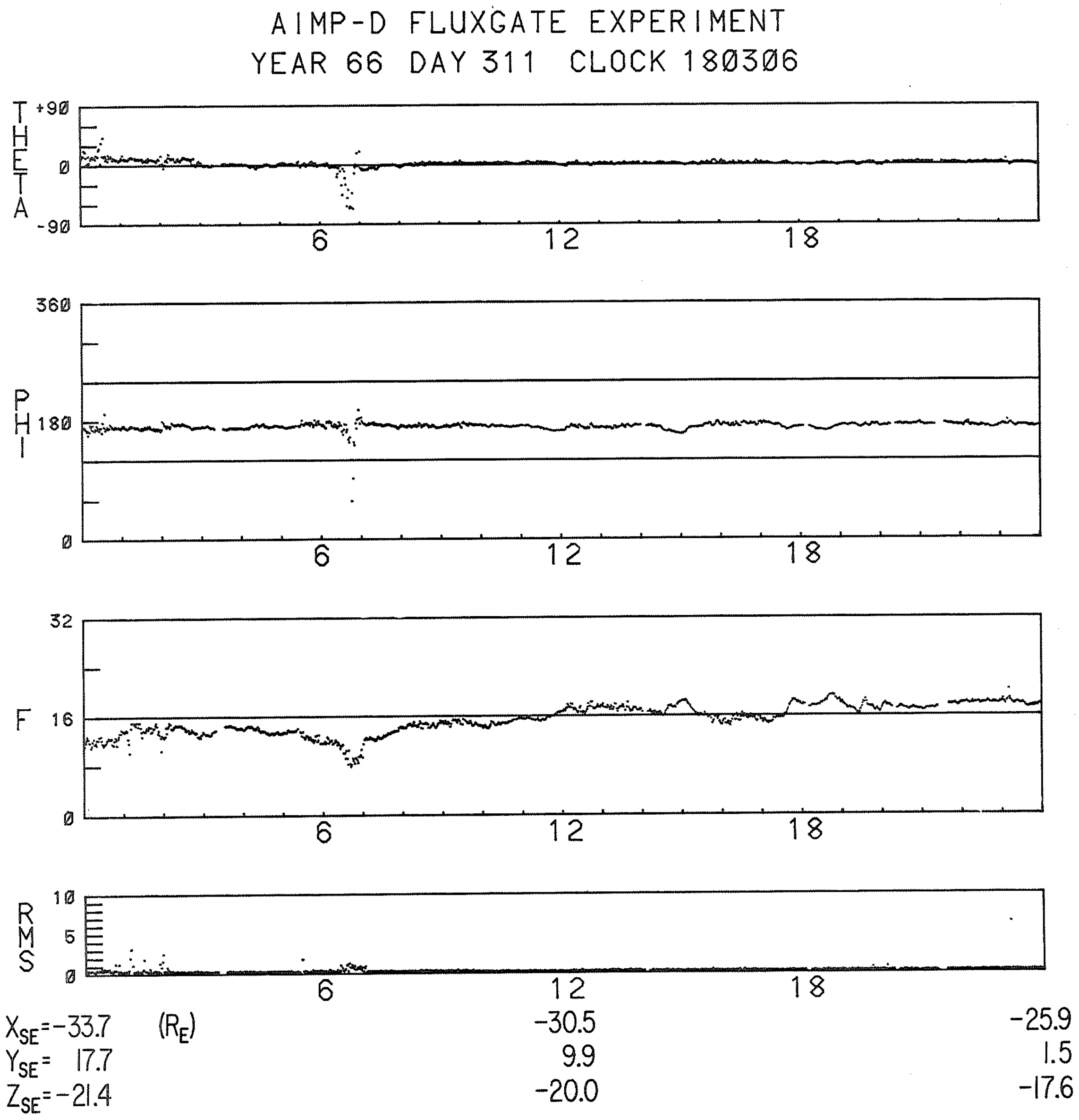


Figure 8. Gerber Sequence Statistics Plot

3. SIMULTANEOUS PLOT

AIMP D and E sequence statistics also can be plotted using the Simultaneous Calcomp Plot Program. This general purpose program is in the library of the IBM 360/75 J and will plot either sequence statistic or detailed data from one to four different satellites for any length time period and on any desired scale. Also it will plot field components as well as F, θ and ϕ if this is desired. The quantities to be plotted, the time interval to be plotted and the scale of the plot are all input on program control cards.

The control cards contain the following information:

	Mnemonics	Columns	Description
Card 1	NSAT	1-5	Number of satellites for which simultaneous data is to be plotted.
	Format: I5		
Card 2	NV	1-5	Number of variables to be plotted for each satellite.
	XTICK	11-19	The distance in inches between tick marks along the abscissa (time axis).
	XLIM	20-28	Maximum distance allowed between two successive points along the abscissa before the pen is lifted.
	Format: I5, 5x, 2F9.7		
Card 3	ATM(1, 1)	1-9	A scaling of beginning sequence count if that is to be used as base instead of time. Otherwise punch in 0.00.
	ATM(2, 1)	10-18	Last two digits of BEGIN year (like 67.0).
	ATM(3, 1)	19-27	BEGIN Month (if necessary, otherwise 0.00).
	ATM(4, 1)	28-36	BEGIN day of year or of month.
	ATM(5, 1)	37-45	BEGIN hour.

	Mnemonics	Columns	Description
	ATM(6, 1)	46-54	BEGIN Minute.
	ATM(7, 1)	55-63	BEGIN second (if necessary, otherwise 0.00).
	Format: 7F9.2		
Card 4	ATM(1, 2)	1-9	END count if used (usually 0.00).
	ATM(2, 2)	10-18	END year.
	ATM(3, 2)	19-27	END Month (usually 0.00).
	ATM(4, 2)	28-36	END day.
	ATM(5, 2)	37-45	END hour.
	ATM(6, 2)	46-54	END minute.
	ATM(7, 2)	55-63	END second (usually 0.00).
	TIS	64-72	The scale in inches/sec (or inches/sequence) along the abscissa. For AIMP'S D and E there are approximately 44 sequences/hour. Thus to plot sequence averages on a scale of one hour/inch requires TIS = .00027778.
	IO	73-79	The number of the input routine.*

*The satellites for which data are plotted and the particular data plotted for each spacecraft depends on the input routines called by the program. The routine to be used for a particular satellite is specified on Card 4 of the set of control cards for that satellite and for a given time interval. If 15 is punched on Card 4 then input routine IN 15 will be used to read data off tape. The input routines currently resident on disk with the program are:

IN 8	IMP F Sequence Averages
IN 9	IMP C Solar Ecliptic (40 sec Fluxgo data)
IN 10	IMP C Solar Magnetic (40 sec Fluxgo data)
IN 11	IMP C Solar Magnetospheric (40 sec Fluxgo data)
IN 12	AIMP D Sequence Averages (with conversion of tape from DCS format)
IN 13	AIMP D Sequence Averages
IN 14	AIMP E Sequence Averages
IN 15	AE Index.

IN 13 and IN 14 read the AIMP D and AIMP E summary tapes. An input routine on cards can be read in along with the control cards which call the program out of the library, and it will override the input routine of that number which is on the disk. For example there is an IN 14 deck which can be used to produce plots of the detailed (16 points/sequence) AIMP E data. There is also a version of the plot program available (on cards) which permits overplotting of data, i.e., the field variables from one satellite can be plotted on the same grids as the corresponding variables from a second satellite. For additional information on the use of the Simultaneous Plot Program see Ridener (1967).

	Mnemonics	Columns	Description
	Format: 7F9.2, F9.7, I7		
Card 5	H(1)	1-6	Height of first variable plotted, in inches (usually F).
	SCMN(1)	7-12	Scale minimum of first variable (like 0.0).
	SCMX(1)	13-18	Scale maximum of first variable (like 20.0).
	LOC(1)	19-20	Location of first variable on the page (1 is top variable, 2 is next to top, etc.).
	H(2)	21-26	Height of second variable (usually θ).
	SCMN(2)	27-32	Scale minimum of second variable (like -90.0).
	SCMX(2)	33-38	Scale maximum of second variable (like +90.0).
	LOC(2)	39-40	Location of second variable on the page.
	H(3)	41-46	Height of third variable (usually ϕ).
	SCMN(3)	47-52	Scale minimum of third variable (like 0.0).
	SCMX(3)	53-58	Scale maximum of third variable (like 360.0).
	LOC(3)	59-60	Location of third variable.

If components are also to be plotted then an additional card must be included with H, SCMN, SCMX and LOC for each component in the same format as above.

Format: 3F6.2, I2, 3F6.2, I2, 3F6.2, I2, 3F6.2, I2.

Card 6	TM(I), I = 1, NV		Number of equally spaced tick marks to be plotted along the ordinate for each variable.

Format: 8F5.0

	Mnemonics	Columns	Description
Card 7	HEAD(1)	1-76	Heading to be printed above the plot of the first variable.
	LIN1(1)	77-80	Whether the plot is to be line or point plot (If 'LINE' is punched, a line plot results, anything else gives a point plot).
	Format: 20A4		
Card 8	HEAD(2)	1-76	Heading for second variable.
	LIN1(2)	77-80	Whether second variable to be line or point plot.
	Format: 20A4		
Card 9	HEAD(3)	1-76	Heading for third variable.
	LIN1(3)	77-80	Whether third variable to be line or point plot.

Each additional variable plotted will require an additional card in the above format.

4. AIMP E MAGNITUDE PLOT

The AIMP E Magnitude plot program was written in FORTRAN language for the IBM 360 computer to produce plots on the Calcomp 770 or 780 Plotter of the detailed AIMP E field magnitude data throughout each successive pass of the spacecraft through the optical shadow of the moon. When the azimuth angle of the position of the satellite in its orbit about the moon is 180°, the spacecraft is in the center of the optical shadow. The 180° times (two per day) for the week covered by a particular summary tape to be plotted are punched onto program control cards. They are obtained from the printout from a Trajectory Tape Scan Program. After the program reads these data it computes a begin time and an end time for each interval by subtracting and adding two hours from and to the 180° times. This interval will be plotted if the corresponding data are on the tape.

There is a separate control card for each plot desired. Each contains a single 180° time (in decimal day time) plus the year (last two digits). The format is: F12.8, 8X, F 2.0. These cards must be in chronological order. If no data is found for a particular time interval the results will be a grid with no plot. Thus cards should only be punched for those passes when at least some portion of the interval desired is on the input tape.

The plots cover a period of four hours (with a scale of 6 in/hour). The magnitude scale runs from 0-20 gamma (5γ/in). The edges of the optical shadow are indicated by vertical lines, and the Universal Time, sequence number, orbital azimuth angle, selenocentric radial distance, and distance from the moon-sun line are all plotted every 15 minutes.

J. SPECTRAL ANALYSIS

Spectral analysis can be performed on the AIMP D and AIMP E magnetic field data using the Generalized Spectral Analysis Programming System. This system, written in FORTRAN for the IBM 360 computer, will perform spectral analysis on any stationary time series sampled at a constant rate. Special input routines are required to handle specific data sets. The printed output lists the autocorrelation, spectral density, coherence, and phase lags for each estimate or lag. There is also an optional output tape for use with the Spectral Analysis Plot Program. Details of the system and its use have been comprehensively documented by Howell (1967).

III. ACKNOWLEDGMENTS

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APPENDIX A

AIMP EXPERIMENTER TAPE FORMAT

Item	Identification	FORTRAN Name	Units	Format
1.	Satellite ID.	ISAT	Decimal	I
2.	Julian day of year	IDAY	Decimal	I
3.	Year	IYR	Decimal	I
4.	Data Acquisition Station	ISTAT	Decimal	I
5.	Analog Tape Number	IATAPE	Decimal	I
6.	A/D Line Indicator	IAD	Decimal	I
	Items 7 thru 50 repeated four (4) times per tape record.			
7.	Decimal time of Year	TIME (I)	Decimal	D
8.	Time Flag	ITFLG (I)	Decimal	I
9.	Sequence Clock	SCLK	Decimal	F
10.	Frame Period	FRRT	Fraction of Decimal Day	F
11.	Experimenter Flag #1	IFLG 1	Decimal	I
12.	Experimenter Flag #2	IFLG 2	Decimal	I
13.	Sequence Identification	ISEQID	Decimal	I
	Items 14 thru 40 repeated eight (8) times per sequence.			
14.	Frame Number	KFRNO (I, J)	Decimal	I
15.	Pre data Flag for ZA	IPRFLG (I, J)	Decimal	I
16.	Raw Data for ZA (Filter #1)	RZAL (I, J)	Comb Filter Number	F
17.	Raw Data for ZA (Filter #2)	RZAZ (I, J)	Comb Filter Number	F
18.	Guardband Flag (ZA)	GFLGZA (I, J)	Decimal	F
19.	Converted Data for ZA	ZA (I, J)	Decimal	F

Item	Identification	FORTRAN Name	Units	Format
20.	Raw Data for YA (Filter #1)	RYA1 (I, J)	Comb Filter Number	F
21.	Raw Data For YA (Filter #2)	RYA2 (I, J)	Comb Filter Number	F
22.	Guardband Flag (YA)	GFLGYA (I, J)	Decimal	F
23.	Converted Data for YA	YA (I, J)	Decimal	F
24.	Raw Data for XA (Filter #1)	RXA1 (I, J)	Comb Filter Number	F
25.	Raw Data for XA (Filter #2)	RXA2 (I, J)	Comb Filter Number	F
26.	Guardband Flag (XA)	GFLGXA (I, J)	Decimal	F
27.	Converted Data for XA	XA (I, J)	Decimal	F
28.	Raw Data for ZB (Filter #1)	RZB1 (I, J)	Comb Filter Number	F
29.	Raw Data for ZB (Filter #2)	RZB2 (I, J)	Comb Filter Number	F
30.	Guardband Flag (ZB)	GFLGZB (I, J)	Decimal	F
31.	Converted Data for ZB	ZB (I, J)	Decimal	F
32.	Raw Data for YB (Filter #1)	RYB1 (I, J)	Comb Filter Number	F
33.	Raw Data for YB (Filter #2)	RYB2 (I, J)	Comb Filter Number	F
34.	Guardband Flag (YB)	GFLGYB (I, J)	Decimal	F
35.	Converted Data for YB	YB (I, J)	Decimal	F
36.	Raw Data for XB (Filter #1)	RXB1 (I, J)	Comb Filter Number	F
37.	Raw Data for XB (Filter #2)	RXB2 (I, J)	Comb Filter Number	F
38.	Guardband Flag (XB)	GFLGXB (I, J)	Decimal	F
39.	Converted Data for XB	XB (I, J)	Decimal	F

Item	Identification	FORTRAN Name	Units	Format
40.	Post Data Flag	IPOFLG (I, J)	Decimal	F
41.	Data Quality Flag	IDQ (I)	Decimal	F
42.	Performance parameter	PP (I)	Decimal	F
43.	PSEUDO Sun Pulse Flag (Frame #2)	IPSP2 (I)	Decimal	I
44.	PSEUDO Sun Pulse Flag (Frame #10)	IPSPIO (I)	Decimal	I
45.	Sun Angle	ISANG (I)	Decimal	I
46.	Spin Period	SPIN (I)	Decimal	F
47.	Sun Time	SUNT (I)	Decimal	F
48.	Moon Time 1	TM1 (I)	Decimal	F
49.	Moon Time 2	TM2 (I)	Decimal	F
50.	Moon Time 3	TM3 (I)	Decimal	F

APPENDIX B

LEAST-SQUARES FIT ROUTINE

The output of an equatorial plane sensor is spin modulated about some base level of counts (DC level), which must be the zero level of the sensor. The ith sample of the output of the sensor in a given telemetry sequence may be expressed by

$$Y_i = A \cos(\omega t - \Psi) + DC \; .$$

The error is

$$E = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} \left(Y_0 - Y_i\right)^2 = \sum_{i=1}^{N} \left[Y_0 - \left(A \cos\left(\omega t_i - \Psi\right) + DC\right)\right]^2 \; .$$

To minimize the deviations set

$$\frac{\delta E}{\delta A} = -2 \sum_{i=1}^{N} \left[Y_i - A \cos\left(\omega t_i - \Psi\right) - DC\right] \cos\left(\omega t_i - \Psi\right) = 0 \; ,$$

and

$$\frac{\delta E}{\delta DC} = -2 \sum_{i=1}^{N} \left[Y_i - A \cos\left(\omega t_i - \Psi\right) - DC\right] = 0 \; .$$

These expressions can be rewritten

$$DC \cos\left(\omega t_i - \Psi\right) + A \sum_{i=1}^{N} \cos^2\left(\omega t_i - \Psi\right) = \sum_{i=1}^{N} Y_i \cos\left(\omega t_i - \Psi\right) \qquad (1)$$

$$N(DC) + A \sum_{i=1}^{N} \cos\left(\omega t_i - \Psi\right) = \sum_{i=1}^{N} Y_i \; . \qquad (2)$$

Given Ψ_k at 4° intervals from 0° to 360° (91 values) as well as ω, t_i and Y_i, (1) and (2) can be solved for A_k and DC_k for each Ψ_k. In each case E_k is computed from

$$E_k = \sum_{i=1}^{N} \left[Y_i - A_k \cos\left(\omega t_i - \Psi\right) + DC_k\right]^2 .$$

The "best" values of A, DC and Ψ will be those corresponding to minimum E_k. Hence because the output from a sensor is linear in A and DC, then assuming ω is known tables (DC_k, A_k and E_k, k = 1, 91) can be constructed from table (Ψ_k, k = 1, 91) and arrays of times and corresponding sensor outputs. The E_k can be scanned for a minimum value, E_k (min.). Then for each sensor the corresponding amplitude A, DC level, and phase angle Ψ will be the best choice for a cosine wave fit to the output for the given sequence. The root-mean-square error of the "best fit" will be

$$RMSE = \sqrt{\frac{E_k\,(\min)}{N}} \; .$$

APPENDIX C

AIMP D AND E EXPERIMENTER FLAGS

The state of the GSFC magnetometer sensor set on AIMP's D and E (i.e. orientation and whether flipping or calibrating) is given by a pair of experimenter flags in Frame 15, Channel 12 of the AIMP Experimenter Tape (items 11 and 12 in Appendix A). In the case of AIMP E these flags also give the range state of the instrument (whether in $\pm 24\gamma$ range or $\pm 64\gamma$ range). These flags are designated 12A and B and are included in the calibration analysis and PDAP printouts as well as being included on the summary tapes (item 3 in Appendix F). The flag definitions are listed below for the two satellites. The terms "normal" and flipped" describe the two terminal orientations of the triaxial sensor sets and are illustrated in Figure 9 (also see Appendix E).

AIMP D

	12A	12B
Normal:		
Usual*	11	12
Flipping	11	13
Calibrating	11	14
Flipped:		
Usual	7	12
Flipping	7	13
Calibrating	7	14

*Usual denotes the condition of the instrument in which the flipper heater and the calibration current are both off.

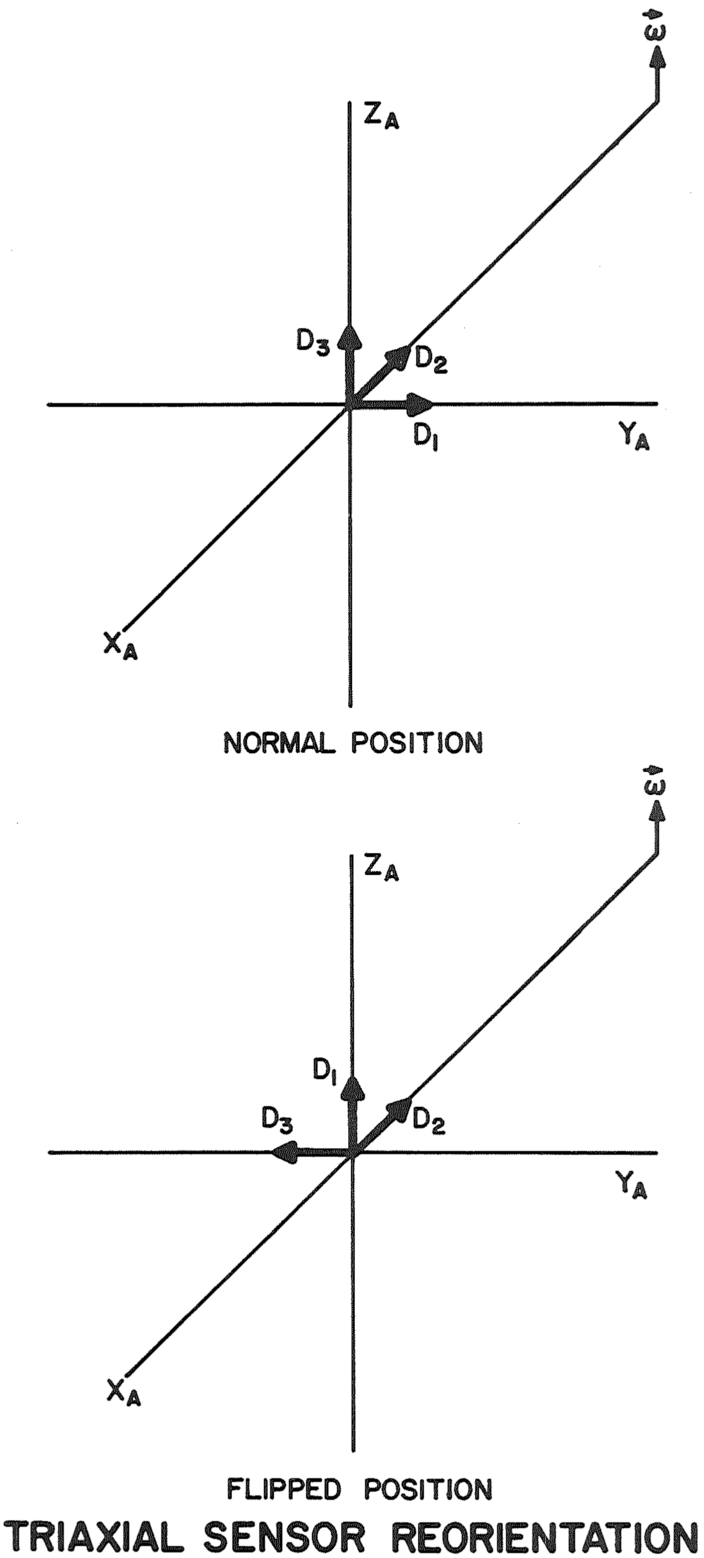

Figure 9. AIMP Magnetometer Sensor Reorientation

AIMP E

	±24γ		±64γ	
	12A	12B	12A	12B
Normal:				
Usual	9	12	8	12
Flipping	9	13	8	13
Calibrating	9	14	8	14
Flipped:				
Usual	5	12	4	12
Flipping	5	13	4	13
Calibrating	5	14	4	14

APPENDIX D

AIMP TRAJECTORY TAPE FORMAT

The trajectory data tapes are 7 channel, 556 bpi, BCD, blocked tapes. The header record is one physical record of 66 characters. The succeeding records will be blocked, 5 logical records per block (physical record).

HEADER RECORD FORMAT

	Characters	Description
1.	1-5	Satellite ID
2.	Date tape was generated.	
	6-7	Year
	8-9	Month
	10-11	Day
3.	12-19	Run Number
4.	Time of first set of coordinates on tape.	
	20-21	Year
	22-24	Decimal Day Count
	25-32	Fraction of day to 8 decimal places
5.	Time of last set of coordinates on tape.	
	33-34	Year
	35-37	Decimal day count
	38-45	Fraction of day
6.	46-53	Time increment between each set of coordinates to 8 places.

	Characters	Description
7.	54-61	Value of 1 earth radius in kilometers, to 0.1 km.
8.	62-66	Value of 1 lunar radius in kilometers, to 0.1 km.

LOGICAL DATA RECORD FORMAT

Characters	Description	Print Program Mnemonic	Printout Label
1. Time of the coordinate set.			
1-2	Year	IYRD	YR
3-5	Decimal day number	IDAYD	DAY
6-13	Fraction of day to 8 places	TIMED	TIME
2. Position vector (X, Y, Z) of the moon in mean equator and equinox of 1950 coordinate system. Components are in kilometers to 0.1 km.			
14	Sign of X		
15-21	X Component	ECX	LUNAXEE
22	Sign of Y		
23-29	Y Component	ECY	LUNAYEE
30	Sign of Z		
31-37	Z Component	ECZ	LUNAZEE
3. Position vector of the moon in geocentric solar ecliptic coordinates. Components are in earth radii, to 0.01 R_E.			
38	Sign of X		
39-42	X Component	SCX	LXSE
43	Sign of Y		
44-47	Y Component	SCY	LYSE
48	Sign of Z		
49-52	Z Component	SCZ	LZSE

Characters	Description	Print Program Mnemonic	Printout Label

4. Position of moon in solar magnetospheric coordinates. Components are in earth radii, to 0.01 R_E.

53	Sign of X		
54-57	X Component	MCX	LXSM
58	Sign of Y		
59-62	Y Component	MCY	LYSM
63	Sign of Z		
64-67	Z Component	MCZ	LZSM

5. Right Ascension and declination of sun referenced to mean equator and equinox of 1950, to 0.1 degree.

68-71	Right Ascension (0.0 to 360.0 degrees)	RADS	SNRA
72	Sign of declination		
73-75	Declination (-90 to 90.0 degrees)	RDDS	SNDEC

6. Position vector of spacecraft in mean equator and equinox of 1950 coordinates. Components are in kilometers, 0.1 km.

76	Sign of X		
77-83	X Component	SEX	SCXEE
84	Sign of Y		
85-91	Y Component	SEY	SCYEE
92	Sign of Z		
93-99	Z Component	SEZ	SCZEE

7. Position vector of spacecraft in solar ecliptic coordinates. Components are in earth radii, to 0.01 R_E.

100	Sign of X		
101-104	X Component	SSEX	XSE

Characters	Description	Print Program Mnemonic	Printout Label
105	Sign of Y		
106-109	Y Component	SSEY	YSE
110	Sign of Z		
111-114	Z Component	SSEZ	ZSE

8. Position vector of spacecraft in solar magnetospheric coordinates. Components are in earth radii, to 0.01 R_E.

115	Sign of X		
116-119	X Component	SSMX	XSM
120	Sign of Y		
121-124	Y Component	SSMY	YSM
125	Sign of Z		
126-129	Z Component	SSMZ	ZSM

9. Position vector of spacecraft in selenocentric solar ecliptic coordinates. Components are in lunar radii, to 0.01 R_L.

130	Sign of X		
131-134	X Component	SLRX	XSSE
135	Sign of Y		
136-139	Y Component	SLRY	YSSE
140	Sign of Z		
141-144	Z Component	SLRZ	ZSSE

10. Geomagnetic latitude and longitude of spacecraft subsatellite point in degrees to 0.1 deg.

145	Sign of Latitude		
146-148	Latitude	GLA	GLAT
149-152	Longitude 0.0 to 359.9 degrees measured eastward from Greenwich meridian.	GLO	GLON

	Characters	Description	Print Program Mnemonic	Printout Label
11.	Right ascension and declination of spacecraft spin axis referenced to mean equator and equinox of 1950, to 0.1 deg.			
	153-156	Right Ascension (0.0 to 359.9)	SCRA	RAEE
	157	Sign of declination		
	158-160	Declination (-90.0 to +90.0 degrees)	SCRD	DECEE
12.	Right ascension and declination of spacecraft spin axis referenced to geocentric solar ecliptic coordinates, to 0.1 deg.			
	161-164	Right Ascension (0.0 to 359.9)	GSRA	RASE
	165	Sign of declination		
	166-168	Declination (-90.0 to +90.0 degrees)	GSRD	DECSE
13.	Right ascension and declination of spacecraft spin axis referenced to solar magnetospheric coordinates, to 0.1 deg.			
	169-172	Right Ascension (0.0 to 359.9)	SMRA	RASM
	173	Sign of declination		
	174-176	Declination (-90.0 to +90.0 degrees)	SMRD	DECSM
14.	177-204	Blank characters.		

APPENDIX

COORDINATE TRANSFORMATIONS

The transformation from the triaxial sensor frame of reference to the frame which rotates with the spacecraft but is stationary with respect to sensor reorientation is given, for sensor outputs (D_1, D_2, D_3), by

$$\begin{bmatrix} BX \\ BY \\ BZ \end{bmatrix}_A = \begin{bmatrix} 0 & -1 & 0 \\ +1 & 0 & 0 \\ 0 & 0 & +1 \end{bmatrix} \begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix}$$

if the sensors are in the normal position, and by

$$\begin{bmatrix} BX \\ BY \\ BZ \end{bmatrix}_A = \begin{bmatrix} 0 & -1 & 0 \\ 0 & 0 & -1 \\ +1 & 0 & 0 \end{bmatrix} \begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix}$$

if the sensors are in the "flipped" position (see Figure 9).

The transformation from $(X, Y, Z)_A$ to the fixed payload $(X, Y, Z)_p$ coordinates is given by

$$\begin{bmatrix} BX \\ BY \\ BZ \end{bmatrix}_p = \begin{bmatrix} \cos \text{DELTA} & -\sin \text{DELTA} & 0 \\ \sin \text{DELTA} & \cos \text{DELTA} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} BX \\ BY \\ BZ \end{bmatrix}_A$$

where for the kth field measurement in a telemetry sequence

$$\text{DELTA} = \frac{2\pi}{T_{spin}} \left[t_s(k) - t_{0A} \right] + \text{SA} - \text{PSHFT} .$$

Here t_s and t_{0A} are sample time and time that the optical aspect (OA) sensor on the spacecraft sees the sun, respectively. SA is the angle from the OA sensor axis to the GSFC magnetometer boom in the direction of satellite rotation, and PSHFT is the instrumental phaseshift. For AIMP D, it has been determined experimentally that for 2 sec. $\leq T_{spin} \leq$ 3 sec. The phaseshift for all three sensors is given to within ±1° by

$$\text{PSHFT} = 5° + 1.5 (2 - T_{spin}) .$$

For AIMP E the correction is more complicated. The phaseshift corrections for the 24γ range are

$$\text{X and Y sensors:} \quad \text{PS} = 6° + 2.5 (2 - T_{spin}) .$$

$$\text{Z sensor:} \quad \text{PS} = 9° + 3.0 (2 - T_{spin}) .$$

The corrections for phaseshift in the 64γ range are:

$$\text{X and Y sensors:} \quad \text{PS} = 4.5° + 2.0 (2 - T_{spin}) .$$

$$\text{Z sensor:} \quad \text{PS} = 5° + 2.0 (2 - T_{spin}) .$$

An additional amplitude correction is necessary in the 24γ range:

$$\text{AMPL}_f = \text{AMPL}_i \left[0.96 + 0.02 (T_{spin} - 2) \right] ,$$

where i and f are initial and final values, respectively, of the amplitude in gammas.

The transformation to solar ecliptic (SE) coordinates is accomplished by rotating the X_p axis through an angle A into the X_{SE} axis and then rotating the

Z_p axis through an angle D into the Z_{SE} axis. Sin A, cos A, sin D and cos D may be expressed in terms of the SE coordinates of a unit spin axis. These coordinates can be computed from the right ascension RASE and declination DECSE of the spin axis in SE coordinates, which are provided on the Explorer 33 trajectory tape, using

$$\mathrm{SAXE} = \cos \mathrm{RASE} \cos \mathrm{DECSE}$$

$$\mathrm{SAYE} = \sin \mathrm{RASE} \cos \mathrm{DECSE}$$

$$\mathrm{SAZE} = \sin \mathrm{DECSE} .$$

Then

$$\cos A = \sqrt{\mathrm{SAYE}^2 + \mathrm{SAZE}^2}$$

$$\sin A = \mathrm{SAXE}$$

$$\cos D = \mathrm{SAZE}/\cos A$$

$$\sin D = \mathrm{SAYE}/\cos A .$$

By combining the A and D rotations in the transformation, the SE field components can then be computed from the payload components using

$$\begin{bmatrix} \mathrm{BY} \\ \mathrm{BY} \\ \mathrm{BZ} \end{bmatrix}_{SE} = \begin{bmatrix} \cos A & 0 & \sin A \\ -\sin A \sin D & \cos D & \cos A \sin D \\ -\sin A \cos D & -\sin D & \cos A \cos D \end{bmatrix} \begin{bmatrix} \mathrm{BX} \\ \mathrm{BY} \\ \mathrm{BZ} \end{bmatrix}_{p}$$

The transformation to solar magnetospheric (SM) coordinates is accomplished at the same time as the transformation to SE coordinates. Since by definition $X_{SM} = X_{SE}$, the only difference in transforming from payload to the SM reference frame from transforming to the SE frame is rotation through a different angle in the YZ-plane. Using the right ascension RASM and declination DECSM of the spin axis in solar magnetospheric coordinates, which are also provided on the

AIMP trajectory tape, and making use of the already computed cos A and sin A, the procedure is analogous to what is done in the SE computations.

Computing

$$\mathrm{SAYSM} = \sin \mathrm{RASM} \cos \mathrm{DECSM}$$

$$\mathrm{SAZSM} = \sin \mathrm{DECSM}$$

$$\cos \mathrm{DM} = \mathrm{SAZSM}/\cos A$$

$$\sin \mathrm{DM} = \mathrm{SAYSM}/\cos A\ ,$$

then

$$\begin{bmatrix} \mathrm{BY} \\ \\ \mathrm{BZ} \end{bmatrix}_{SM} = \begin{bmatrix} -\sin A \sin \mathrm{DM} & \cos \mathrm{DM} & \cos A \sin \mathrm{DM} \\ \\ -\sin A \cos \mathrm{DM} & -\sin \mathrm{DM} & \cos A \cos \mathrm{DM} \end{bmatrix} \begin{bmatrix} \mathrm{BX} \\ \mathrm{BY} \\ \mathrm{BZ} \end{bmatrix}_{P}$$

APPENDIX F

FORMAT OF AIMP SUMMARY DATA TAPES

The AIMP summary data tapes are produced on an IBM 360 computer. They are 9-track, 1600 BPI binary tapes that will contain one file of data unless otherwise specified, with standard IBM 360 integer and real single and double precision 32-bit words. Each logical record on the tapes contains summary magnetic field data from one telemetry sequence. The tapes are system blocked with 4 logical records to a physical record.* Each logical record contains 19 double precision words and 232 single precision words for the AIMP D tapes (for a total of 270 32-bit words or 1080 bytes) and 19 double precision words and 235 single precision words for the AIMP E tapes (for a total of 273 32-bit words or 1092 bytes). The physical record length is then a factor of 4 larger in each case. On IBM 360 these tapes can be read one logical record at a time using the appropriate DCB parameters in the DD specifications for that input unit. An example of this for AIMP E tapes is as follows:

DCB = (,BLKSIZE = 4388, LRECL = 1096, RECFM = VB).

The format of each logical record is given below.

Quantity	Word No.	Single or Double Precision	Integer or Real
1. Decimal day of sequence†	1-2	1D (double)	R (real)
2. Hour of sequence	3	1S (single)	I (integer)
3. Minute of sequence	4	1S	R
4. Sequence number (clock)	5	1S	I
5. Year	6	1S	I
6. Spin period (seconds)	7-8	1D	R
7. Optical aspect time (seconds)	9-10	1D	R
8. Spin axis right ascension (deg. solar ecliptic)	11	1S	R

*This applies to all summary tapes after the smoothing stage of processing (See Section II C).
†The sequence decimal day time that is written on the summary tapes is actually the time at the center of the GSFC Magnetometer sampling interval in the sequence. It is the time of frame 0, Channel 0 + 39.4671 seconds.

	Quantity	Word No.	Single or Double Precision	Integer or Real
9.	Spin axis declination (deg.-SE)	12	1S	R
10.	Spin axis right ascension (deg. solar magnetospheric)	13	1S	R
11.	Spin axis declination (deg.-SM)	14	1S	R
12.	16 sample times (sec. since beginning of year)	15-46	16D	R
13.	16 values of magnetic field magnitude (gammas)	47-62	16S	R
14.	Sequence average field magnitude (gammas)	63	1S	R
15.	Magnitude standard deviation (gammas)	64	1S	R
16.	F Ratio*	65	1S	I
17.	16 values of BX_A† (gammas)	66-81	16S	R
18.	16 values of BY_A	82-97	16S	R
19.	16 values of BZ_A	98-113	16S	R
20.	16 values of BX_p† (payload coord. components-gammas)	114-129	16S	R
21.	16 values of BY_p	130-145	16S	R
22.	16 values of BZ_p	146-161	16S	R
23.	Sequence average $(BX, BY, BZ)_p$ components (gammas)	162-164	3S	R
24.	$(X, Y, Z)_p$ RMS deviations (gammas)	165-167	3S	R

*This magnitude ratio is defined by

$$\text{F RATIO} = \left(\frac{\text{sequence total field RMS deviation}}{\text{sequence average total field magnitude}}\right) \times 100.$$

†The $(BX, BY, BZ)_A$ components are relative to the triaxial magnetometer sensor coordinate axes rotating with the spacecraft. Payload components $(BX, BY, BZ)_p$ are relative to a fixed frame of reference centered in the spacecraft with the Z axis along the spin axis and the X axis in the plane defined by the spin axis and the satellite-sun vector.

Quantity	Word No.	Single or Double Precision	Integer or Real
25. θ_p, Ψ_p (payload field latitude and azimuth - deg.)	168-169	2S	R
26. 16 values of BX_{SE} (solar ecliptic components-gammas)	170-185	16S	R
27. 16 values of BY_{SE}	186-201	16S	R
28. 16 values of BZ_{SE}	202-217	16S	R
29. Sequence average (BX, BY BZ)$_{SE}$ components (gammas)	218-220	3S	R
30. (X, Y, Z)$_{SE}$ RMS deviations (gammas)	221-223	3S	R
31. C Ratio*	224	1S	I
32. θ_{SE}, ϕ_{SE} (SE field latitude and azimuth-deg.)	225-226	2S	R
33. 16 values of Y_{SM} (solar magnetospheric components-gammas)	227-242	16S	R
34. 16 values of Z_{SM}	243-258	16S	R
35. Sequence average (Y, Z)$_{SM}$ components (gammas)	259-260	2S	R
36. Data quality flag	261	1S	I
37. Experiment flags 12 A, B	262-263	2S	I
38. No. of digitized data points in sequence.	264	1S	I
39. Satellite position (X, Y, Z)$_{SE}$ (R_E)	265-267	3S	R
40. Satellite position (Y, Z)$_{SM}$ (R_E)	268-269	2S	R

*The component ratio is defined by

$$\text{C RATIO} = \left(\frac{\text{sum of component RMS deviations}}{3\sqrt{\overline{BX}^2 + \overline{BY}^2 + \overline{BZ}^2}}\right) \times 100,$$

where $\overline{BX}$, $\overline{BY}$ and $\overline{BZ}$ are the sequence average solar ecliptic coordinate field components.

Quantity	Word No.	Single or Double Precision	Integer or Real
If AIMP D tape:			
41. Sequence ID (1, 2, 3 or 4)	270	1S	I
If AIMP E tape:			
41. Selenocentric satellite position $(X, Y, Z)_{SSE}$ (R_L)	270-272	3S	R
42. Sequence ID (1, 2, 3 or 4)	273	1S	I

APPENDIX G

SHADOW PLOT PROGRAM PRINTOUT AND PLOT DESCRIPTIONS

1. Detailed Explanation of the Printout

The first line of output contains the sequence number of the first shadow data and the length of the shadow read from the input card along with the numbers of the first and last sequences of the interval to be processed (ISEQI and ISEQF respectively). Following this line there will be a variable number of lines containing the sequence numbers read from the tape while searching for the first interval to be processed. When the first sequence in this interval is reached a line will be printed containing the decimal day time of the beginning of the shadow from the input card along with the time of the start and end of the interval being processed.

Next, beginning on a new page, will be the raw data directly from the summary tape. Above the column headings at the top of the page, the geocentric spacecraft position is given in both solar ecliptic and solar magnetospheric coordinates. The six numbers given for solar ecliptic coordinates are, respectively, X_{se}, Y_{se}, Z_{se}, R, θ_{se} and ϕ_{se}. The four numbers for solar magnetospheric coordinates are Y_{sm}, Z_{sm}, θ_{sm}, ϕ_{sm} respectively. Since $X_{sm} = X_{se}$ and $R_{sm} = R_{se} = R$ these numbers are only given once.

The parameters contained in the listing of the raw data are identified by the headings at the top of each column. The meanings of the column headings are as follows:

DECDAY	Decimal day time at middle of frame 8 in sequence.
SEQ	Sequence number.
YR	Calendar year (-1900).

A sequence is not used if the number of good 5 second measurements is less than 13, (a normal sequence has 16 such points). The sequence is also rejected if the magnitude of the field is greater than 100 gammas or is negative, if the absolute value of the latitude angle of the field is greater than 90 or if the longitude angle of the field is not between 0° and 360°. Note that all angles are given in degrees, distances in lunar radii and fields in gammas.

The next two pages of output contain information about the angular correction in lunar shadow and are written out in the subroutine CRXT. First is a list of the input parameters used in approximating the spin period as a function of time (these parameters are discussed in section F). The method of empirically fitting an expression of the form A + B exp (T/To) was described by Taylor (1968). Other quantities listed on this page are as follows:

PFSEQ4	is the calculated spin period at the time of the first good sun time after the shadow.
SL	is the sequence length in seconds.
CPS	is the actual frequency of the 800 hertz clock in hertz.
PF	is the calculated spin period at the time of egression from the optical shadow.
FN	is the estimated number of rotations made by the spacecraft between the last sun sensor reading before the shadow and the first reading after the shadow plus 0.5.
RSS	Selenocentric radial distance of the spacecraft.
XSS, YSS, ZSS	Cartisian coordinates of selenocentric solar ecliptic spacecraft position. (X is toward sun, Z toward North ecliptic pole and Y in dusk meridian).
BXP, BYP BZP	Payload X, Y, Z components of sequence average magnetic field. (Z is along spacecraft spin axis, X is perpendicular to Z in the plane containing the spacecraft-sun line and the spin axis and Y is in the direction of $\hat{Z} \times \hat{X}$).
FP	is the magnitude of the component average field i.e. $FP = \sqrt{BXP^2 + BYP^2 + BZP^2}$.
DLT	is the Pythagorean sum of the component standard deviations of the sequence average, i.e. $DLT = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}$.
AVF	is the sequence average of the individual field magnitude measurements.
THP	is the latitude angle of the component average field THP = ARSIN (BZP/FP).
PSI	is the longitude angle of the component average field PSI = ATAN2 (BXP, BXP).
NG	is the number of good points in the average.

BXS, BYS, BZS	Solar ecliptic X, Y, Z components of sequence average magnetic field.
FAS, THS, PHS	Magnitude, latitude angle and longitude angle of average field in solar ecliptic coordinates.

An asterisk (*) is added at the end of the line of each sequence considered to be reliable.

N	is the largest integer contained in FN and represents the true number of revolutions made by the spacecraft between the last sun reading before the shadow and the first one after it.
RO	is the calculated number of rotations between good sequence 4's where the suntime is measured.
C	is the calculated number of rotations made by the spacecraft while in the optical shadow.
A and B	are the estimated values of the parameters in the empirical expression for the spin period.

The next values listed for

A, B, and TO	are the calculated values of these parameters. Occasionally there will appear a note that something was not 0 after 10 iterations. This means that the results are inaccurate and invariably arises because some of the input parameters are in error.

The next line gives the net rotation between the middle of the last sequence before the shadow in which the sun aspect was measured and the middle of the first such sequence after the shadow. This number should be equal to RO written out above.

RO and RI	are the number of spacecraft rotations made since the middle of the good sequence 4 before the shadow at entrance into and emergence from the shadow respectively. Note this RO is different from the one used earlier.

The next page presents the corrected field values. The first four columns give the sequence number, actual number of rotations, the number of rotations used in the original analysis of the spacecraft data and the angular error in this original analysis. The remaining twelve columns give the corrected magnetic field data when it is available. (If the data is missing or bad these twelve columns are left blank.) The quantities printed are as follows:

XSS, YSS and ZSS	are selenocentric solar ecliptic coordinates of the spacecraft position.
BX, BY and BZ	are corrected payload components of the sequence average magnetic field. Note that BZ should be the same as BZP in the Raw data.
AVF	is the average of the field magnitudes, AVF is the same as in the raw data.
RMSE	is Pythagorean sum of the standard deviation of the three components (same as DLT in raw data).
FAV, PSI and THE	are the magnitude, longitude angle and latitude angle respectively of the corrected payload magnetic field vector. FAV is the same as FP and THE is same as THP in raw data.
DDAY	is the decimal day at the middle of the data used in the sequence average. It is the same as DECDAY in raw data.

Following the last sequence of corrected data is a line which compares the first azimuth angle after the shadow (this angle does not need to be corrected) with the last corrected azimuth angle. If the magnetic field remained constant during the period over which these two measurements were made then the difference between the good angle and the corrected angle should be zero.

The next page has the average fields before, during and after the shadow. A point is considered in the wake region if

$$\text{RHO}\left(= \sqrt{\text{YSS}^2 + \text{ZSS}^2}\right)$$

is greater than 1 - 0.2 * XSS. (Since XSS is negative in the lunar wake this region is larger than the optical shadow.)

The quantities tabulated are defined as follows:

BX, BY, BZ and RMSE	the average values of the corresponding quantities on the preceding page of printout.
F	is the average value of FAV on preceding page.

SDBX, SDBY SDBZ, SDF and SDR	are the standard deviations of Bx, By, Bz, F and RMSE respectively.
FAV, TAV and PAV	are the magnitude, latitude and longitude angles of the average field vector.
N	is the number of points in the average.
SEQI and SEQF	are the starting and ending sequence numbers respectively for the average.
ALPH	is the angle between the magnetic field vector and the X axis. Mathematically it is defined by $$ALPH = \frac{BY}{\lvert BY \rvert} TAN^{-1}\left(\frac{\sqrt{BY^2 + BZ^2}}{BX}\right).$$
BETA	is the azimuthal angle of the field about the X axis measured from the ecliptic plane. Mathematically it is defined by $$BETA = TAN^{-1}\left(\frac{BZ}{BY}\right).$$

The bulk of the remaining printout is a listing of the corrected data in the three natural coordinate systems computed using the average field before, during and after the shadow as listed on the page just described. Asterisks at the extreme right hand end of a line indicate that the spacecraft was in the optical shadow (* is written when RHO ≤ 1). The following is a description of the quantities printed.

DECDAY and SEQ	are the decimal day and sequence number respectively.
BX, BY and BZ	are the sequence average field components in a coordinate system where the plane containing the X axis (sun direction) and the average magnetic field vector is taken to be the x y plane and the z direction is in the direction of $\vec{X} \times \vec{B}$.
DBX/B, DBY/B and DBZ/B	are the deviations of the field components from the average normalized to the magnitude of the average field, i.e. $DBX/B = (Bx - \langle BX \rangle)/\langle B \rangle$ where $\langle\ \rangle$ indicates the average and $\langle B \rangle = \sqrt{\langle BX \rangle^2 + \langle BY \rangle^2 + \langle BZ \rangle^2}$. DBY/B and DBZ/B have analogous definitions.

F, THE and PHI	are the spherical coordinates of the field in the natural system of coordinates.
BX/M, BY/M, BZ/M and F/M	are the 3 cartesian components and the field magnitude (respectively) normalized by the maximum field observed during the entire pass.
XLUN, YLUN and ZLUN	are the cartesian components of the spacecraft position vector in the natural coordinate system.
RLUN, TLUN and PLUN	are the spherical coordinates of the spacecraft position vector in the natural coordinate system.

Following the listing of the data in the third of the natural coordinate systems where the reference field used is the field after the shadow is information about the completion of the plots. The plots are numbered sequentially with each pass producing 2 plots: the first a plot of the parameters as a function of time and the second a vector plot in two projections of the spacecraft orbit.

2. Detailed Explanation of the Plots

Each pass through the lunar shadow will normally produce two plots. A sample is shown in Figure 7. The first consists of plots of nine different quantities as a function of sequence number and the second consists of two orthogonal projections of the magnetic field vectors plotted along the spacecraft orbit. (The vector plot cannot be done when trajectory data are missing.)

The field vs sequence plots are largely self-explanatory. The plotted quantities are defined as follows:

F, T, P — are the magnitude, minus the latitude and 360° minus the longitude in spacecraft coordinates. This corresponds to solar ecliptic coordinates if the spacecraft spin axis is directed toward the south ecliptic pole. Scales are 5γ/inch for F and 100°/inch for the two angles.

PR — is a crude estimate of the plasma pressure calculated assuming that $\rho + B^2/8\pi$ is a constant. PR is a dimensionless quantity defined as follows:

$$PR = \frac{B\ max^2 - B^2}{B^2\ max - \langle B \rangle^2}$$

It is plotted on a scale of 2.5 units/inch.

DC and DF	are the component and magnitude standard deviations found for the sequence average. Both are plotted on a scale of 2.5γ/inch.
BX, BY and BZ	are the magnetic field components in the natural coordinate system. The reference field used to determine this coordinate system is written in the heading for these 3 plots. The scale for each component is 10γ/inch.

At the bottom of the plot the spacecraft position is printed out in two different coordinate systems. The first 3 numbers are the x, y and z components of the spacecraft position vector in the natural coordinate system. The next two are the radial distance and solar ecliptic longitude of the spacecraft. The final number is the Universal Time.

All the time scales for these nine plots are the same, 10 sequences/inch, a tick mark every 10 sequences and the sequence number is specified below the P plot and also below the BX plot. The region of the optical shadow is delimited by the two vertical lines drawn across each section of the plot.

The vector plots are also largely self-explanatory, but a few details should be noted. In particular the coordinate system used is the natural one so that the XY plane is the plane of the sun direction and the average field before the shadow. The vectors plotted are the projection of the individual field measurements into the appropriate plane. The scale used is 5γ/inch so that a vector 1" long implies that the projection of the field vector into that plane is 5γ in magnitude. The average vector field used to determine the natural coordinates is represented by its projection in the upper left hand corner of each plot.

The program typically takes about 3 minutes to process a complete summary tape and generates approximately 12 pages of printout for each shadow pass processed. On the calcomp each pass takes about 8 minutes to plot and uses almost 3 feet of 30" paper.

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APPENDIX H

IBM SYSTEM 360 DATA DEFINITION CARDS

To facilitate the use of the programs in the AIMP DATA PROCESSING SYSTEM, typical DD cards required by each of the programs are listed in the following sections.

1. CALIBRATION PROGRAM

```
//GO.FT08F001   DD DSNAME=RAWIN,UNIT=2400-7,                        *
//              VOLUME=SER=Z1438,                                   *
//              DCB=(,RECFM=F,BLKSIZE=2293,DEN=1,TRTCH=ET),         *
//              LABEL=(,BLP),DISP=(OLD,KEEP)
//GO.FT09F001   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,               *
//              BLKSIZE=3429),SPACE=(CYL,(10,5))
//GO.FT10F001   DD DSNAME=RAWTOO,UNIT=2314,                         *
//              DCB=(,RECFM=V,LRECL=2297,BLKSIZE=2301),             *
//              DISP=(NEW,DELETE),SPACE=(CYL,(10,5))
```

Input is the Experimenter Tape on unit FT08.

2. PDAP

```
//GO.FT06F001   DD SPACE=(CYL,(10,5))
//GO.SYSIHC     DD SYSOUT=A
//GO.FT08F001   DD DSNAME=RAWIN,UNIT=2400-7,                        *
//              VOLUME=SER=Z0614,                                   *
//              DCB=(,RECFM=F,BLKSIZE=2293,DEN=1,TRTCH=ET),         *
//              LABEL=(1,BLP),DISP=(OLD,KEEP)
//GO.FT09F001   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,               *
//              BLKSIZE=3429),SPACE=(CYL,(10,5))
//GO.FT10F001   DD DSNAME=RAWTOO,UNIT=2314,                         *
//              DCB=(,RECFM=V,LRECL=2297,BLKSIZE=2301),             *
//              DISP=(NEW,DELETE),SPACE=(CYL,(10,5))
//GO.FT11F001   DD DSNAME=SUMMARY,UNIT=2400,                        *
//              VOLUME=SER=Z0617,                                   *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB),            *
//              LABEL=(,BLP),DISP=(NEW,KEEP)
```

```
//GO.FT12F001   DD DUMMY,DSNAME=SC4020,UNIT=2400-7,                  *
//              VOLUME=SER=Z632,                                      *
//              DCB=(LRECL=1200,BLKSIZE=1200,DEN=1),                  *
//              LABEL=(,BLP),DISP=(NEW,KEEP)
//GO.FT13F001   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,                 *
//              BLKSIZE=3429),SPACE=(CYL,(10,5))
//GO.FT14F001   DD DSNAME=DSKTRAJ,UNIT=2314,                          *
//              DCB=(,RECFM=V,LRECL=1024,BLKSIZE=1028),               *
//              DISP=(NEW,DELETE),SPACE=(CYL,(10,5))
//GO.FT15F001   DD DSNAME=AIMPT,UNIT=2400-7,DISP=(OLD,KEEP),          *
//              LABEL=(,BLP),DCB=(,RECFM=U,BLKSIZE=1020,              *
//              DEN=1,TRTCH=ET),VOLUME=SER=Z0613
//GO.FT16F001   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,                 *
//              BLKSIZE=3429),SPACE=(CYL,(10,5))
//GO.FT17F001   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,                 *
//              BLKSIZE=3429),SPACE=(CYL,(10,5))
```

Inputs are the Experimenter Tape on FT08 and the Trajectory Tape on FT15. Output is the Raw Summary Tape on FT11.

3. SC 4020 SEQUENCE STATISTIC PLOT

```
//GO.FT10F001   DD DSNAME=SUMMARY,                                    *
//              DISP=(OLD,KEEP),                                      *
//              UNIT=2400,                                            *
//              LABEL=(,BLP),                                         *
//              VOLUME=SER=Z1301,                                     *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
//GO.SC4020     DD UNIT=2400-7,                                       *
//              LABEL=(,BLP),                                         *
//              VOLUME=SER=Z0640,                                     *
//              DCB=(LRECL=1200,BLKSIZE=1200,DEN=1)
```

Input is the Raw Summary Tape on FT10. Output is the Plot Tape on SC 4020 unit.

4. AUTOMATIC SMOOTHING

```
//GO.FT09001    DD SYSOUT=A,SPACE=(CYL,(10,5)),                       *
//              DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3429)
```

```
//GO.FT10F001   DD DSNAME=NEWSUMM,UNIT=2400,                        *
//               LABEL=(,BLP),DISP=(NEW,KEEP),                       *
//               DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB),            *
//               VOLUME=SER=Z613
//GO.FT11F001   DD DSNAME=SUMMARY,UNIT=2400,                         *
//               VOLUME=SER=Z1309,                                   *
//               DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB),            *
//               LABEL=(,BLP),DISP=(OLD,KEEP)
//GO.FT12F001   DD SYSOUT=(F,FILMTRAN),SPACE=(CYL,(10,5)),          *
//               DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3429)
//GO.FT13F001   DD SYSOUT=(F,FILMTRAN),SPACE=(CYL,(10,5)),          *
//               DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3429)
//GO.SC4020     DD UNIT=2400-2,LABEL=(,BLP),VOLUME=SER=Z1438,        *
//               DCB=(LRECL=1200,BLKSIZE=1200)
```

Input is the Raw Summary Tape on FT11. Outputs are the Smoothed Summary Tape on FT10, the Detailed Data Plot Tape on SC 4020 unit, and printout on microfilm (see Section 12 this Appendix).

5. SORT

```
//SORT.SORTIN   DD UNIT=2400,LABEL=(,BLP),                           *
//               VOLUME=(,,,2,SER=(Z0622,Z0623)),                    *
//               DISP=(OLD,KEEP),                                    *
//               DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
//SORT.SORTOUT DD VOLUME=SER=Z0630,                                  *
//               UNIT-2400,                                          *
//               DISP=(NEW,KEEP),                                    *
//               LABEL=(,BLP),                                       *
//               DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
```

Input is the Smoothed Summary Tape on SORTIN and output is the Sorted Summary Tape on SORTOUT.

6. OVERLAP REMOVAL

```
//GO.FT10F001   DD DSNAME=OUTPU5,                                    *
//               DISP=(OLD,KEEP),                                    *
//               UNIT=2400,                                          *
//               LABEL=(,BLP),                                       *
//               VOLUME=SER=Z1098,                                   *
//               DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
```

```
//GO.FT11F001   DD DSNAME=NEWOU5,                                     *
//              DISP=(NEW,PASS),                                      *
//              UNIT=2400,                                            *
//              LABEL=(,BLP),                                         *
//              VOLUME=SER=Z1312,                                     *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
//GO.FT10F001   DD DSNAME=NEWOU5,                                     *
//              DISP=(OLD,KEEP),                                      *
//              LABEL=(,BLP),                                         *
//              VOLUME=REF=NEWOU5,                                    *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
```

Input is the Sorted Summary Tape on FT10. Output is the Sorted and Overlap Removed (Final) Summary Tape on FT11.

7. SHADOW PLOT

The input tape is an unblocked summary tape. It should have had the overlap removed so that there is no redundant data. A typical DD card is as follows:

```
//GO.FT08F001   DD DSNAME=INDATA,DISP=(OLD,KEEP),LABEL=(,BLP),        *
//              UNIT=2400,DCB=(,BLKSIZE=4404,LRECL=1100,              *
//              RECFM=VB,DEN=2),VOLUME=SER=Z553
```

The plot tape is the standard calcomp. 7 track output tape. A suitable DD card is as follows:

```
//GO.PLOTAPE    DD DSNAME=CALCOMP,LABEL=(,BLP),                       *
//              DISP=(NEW,KEEP),UNIT=2400-7,DCB=(,DEN=1),             *
//              VOLUME=SER=Z551
```

8. HOURLY AVERAGING

```
//GO.FT07F001   DD DSNAME=DECK,SYSOUT=B
//GO.FT10F001   DD DSNAME=INDATA,DISP=(OLD,KEEP),                     *
//              UNIT=2400,VOLUME=SER=Z1435,LABEL=(,NL),               *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
```

Input is the Final Summary Tape on FT10. Output is the deck of hourly average cards punched by the program. These can be input to the Hourly Average Plot Program. Output of that program is a Plot tape:

```
//GO.PLOTAPE    DD DSNAME=CCALCOMP,LABEL=(,BLP),                      *
//              DISP=(NEW,KEEP),UNIT=2400-7,DCB=(,DEN=1),             *
//              VOLUME=SER=Z1112
```

9. DETAILED SE OR SM PRINTOUT

```
//GO.FT08F001   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,                 *
//              BLKSIZE=3429),SPACE=(CYL,(10,5))
//GO.FT09F001   DD DSNAME=AFHEHFIL,UNIT=2400-7,DISP=(NEW,KEEP),       *
//              LABEL=(,BLP),DCB=(BLKSIZE=133,RECFM=U,                *
//              DEN=1,TRTCH=ET),VOLUME=SER=Z620
//GO.FT11F001   DD DSNAME=OUTPUT,                                     *
//              DISP=(OLD,KEEP),                                      *
//              UNIT=2400,                                            *
//              LABEL=(,BLP),                                         *
//              VOLUME=SER=Z1319,                                     *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
```

Input is the Final Summary Tape on FT11.

10. GERBER PLOT

```
//GO.FT10F001   DD DSNAME=SUMMIN,                                     *
//              DISP=(OLD,KEEP),                                      *
//              UNIT=2400,                                            *
//              LABEL=(,BLP),                                         *
//              VOLUME=SER=Z1102,                                     *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
//GO.GERBER     DD UNIT=2400-7,LABEL=(,BLP),VOLUME=SER=Z1103
```

Input is a post-smoothing summary tape on FT10. Output is the Plot Tape on the GERBER unit.

11. AIMP E MAGNITUDE PLOT

```
//GO.FT10F001   DD DSNAME=NEWOUT,                                     *
//              DISP=(OLD,KEEP),                                      *
//              UNIT=2400,                                            *
//              LABEL=(,BLP),                                         *
//              VOLUME=SER=Z1306,                                     *
//              DCB=(,BLKSIZE=4404,LRECL=1100,RECFM=VB)
```

```
//GO.PLOTAPE    DD DSNAME=CCALCOMP,LABEL=(,BLP),                      *
//                 DISP=(NEW,KEEP),UNIT=2400-7,DCB=(,DEN=1),          *
//                 VOLUME=SER=Z1307
```

Input is the AIMP E Final Summary Tape on FT10. Output is the Plot Tape.

12. PRINTOUT ON MICROFILM

The facility to generate a 4020 microfilm tape in place of the normal print-out has been incorporated into several of the programs of the AIMP D and E Processing System. The only steps required to implement this process are a change in each of the effected DD cards.

To obtain microfilm:

```
//GO.FTXXF00I   DD SYSOUT=(F,FILMTRAN),DCB=(RECFM=VBA,                 *
//                 LRECL=137,BLKSIZE=3429),SPACE=(CYL,(10,5))
```

To obtain normal printout:

```
//GO.FTXXF00I   DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137),                 *
//                 BLKSIZE=3429),SPACE=(CYL,(10,5))
```

XX=FORTRAN unit number used in write statements.

When submitting the job, it should be noted on the job request slip that CLASS "F" output is required and specify the tape number to be used as an output tape. When using this facility an override of the normal output unit (FT06) should be avoided as all system messages including storage dumps are written on FT06.

Any other programs that must read the AIMP Summary Tapes will require DD specifications for the input unit identical to those given in the examples listed. Similarly, specifications for output plot tapes will be the same as those given in the examples.